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FLUTTER TESTS ON SB2U MODEL

IN 16-FOOT TUNNEL

By Theodore Theodorsen, R. P. Coleman, and N. H. Smith

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Langley Field, Va.

NACA

WASHINGTON

L - 657

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

FLUTTER TESTS ON SB2U MODEL IN 16-FOOT TUNNEL

By Theodore Theodorsen, R. P. Coleman, and N. H. Smith

SUMMARY

Tests were conducted in the 16-foot NACA tunnel at Langley Field to determine the flutter characteristics of the SB2U-2 airplane. These tests were originally planned as a desirable check of recommendations based on calculations and submitted to the Navy and the manufacturer subsequent to the occurance of flutter in high-speed dives. The tests were also, at that time, considered as a useful check on the theory itself. A further purpose of the tests was to study the behavior of the airplane just below the flutter speed, a problem which has been the subject of much speculation on the practicability of flutter testing in flight. Since the validity of flutter calculations has been very well established since that time, the second object was, at present, considered the primary purpose of the tests.

The tests herein reported consisted of an extensive series of vibration tests conducted for a range of airspeeds up to 140 miles per hour. The model was subjected to an alternating force produced by a vibrator, the frequency

of which was changed throughout the range from 500 to 2000 cpm. The resulting vibration response patterns were recorded and plotted as a function of airspeed and imposed frequency.

It was found from the studies herein reported that the response amplitude increased irregularly and more gradually than expected, the increase starting at a speed about two-thirds of the predicted flutter speed. The model was not tested to destruction since the skin exhibited a disturbing buckling at high speed and it was feared that the model might be destroyed due to local skin failure.

INTRODUCTION

Early in 1939, several cases of flutter were reported on the SB2U-2 airplane. An airplane furnished to the NACA was put through a series of vibration tests at Langley Field. These tests showed that the torsion frequency was rather low, 1100 cpm. The lowest bending frequency was found to be normal with a frequency of about 700 cpm. In consequence, however, the ratio of the bending frequency to the torsion frequency was high, a condition inducive to low values of flutter speed. In the airplanes experiencing flutter, the aileron balance weights were confined to the tip section only. Inspection showed that at least on one occasion the flutter had occurred inboard since the damage appeared near the middle of the aileron. The observed flutter speed, as reported by three pilots, was near 400 miles per hour true speed. This value checked very well with that obtained by calculation based on tests conducted for this purpose at Langley Field in the spring of 1939.

The following recommendations were at that time submitted to Vought-Sikorsky Aircraft. The flutter speed should be increased in the order of 20 percent, that is, from 400 to about 500 miles per hour by the following means: (a) increase torsional frequency of wing to at least 1320 cpm, and (b) provide a more uniform distribution of the aileron counterbalance weights. It was further tentatively recommended that a quarter-scale model be built in order not to miss the opportunity of studying this case in all its consequences. These recommendations were considered and approved at a meeting at the Navy Department on March 20, 1939, of representatives from the Vought-Sikorsky Aircraft, the Navy, and the NACA.

Since this time, Mr. S. J. Loring (reference 1) has very thoroughly studied the flutter characteristics of the SB2U airplane. At the request of the Navy, a flutter model was built by Vought-Sikorsky Aircraft. The design and characteristics of this flutter model have been given by Mr. S. J. Loring (references 2 and 3). This model was submitted to Langley Field in November 1942 for the purpose of conducting wind-tunnel tests on flutter characteristics.

The NACA wishes to acknowledge the generous cooperation of the Navy, the Glenn L. Martin Company, and the Vought-Sikorsky Aircraft, manufacturer of the airplane. The collaboration of Lt. G. V. Schliestett and Mr. R. C. F. Bartels, of the Bureau of Aeronautics, Navy Department; Messrs. W. B. Bergen, W. W. Bender, Jr., W. G. Purdy, and J. P. Paine, of the Glenn L. Martin Company; and Mr. F. B. Sandgren, of Vought-Sikorsky Aircraft, is especially appreciated. Recommendations are given in regard to a final test on the flutter speed.

DESCRIPTION OF TEST EQUIPMENT AND METHOD

Flutter tests on the SB2U model were conducted in the 16-foot tunnel of the NACA Langley Field Laboratories. The model as installed is shown in the photographs (figs. 1(a), (b), and (c)). A dozen small pickups were distributed within the wing structure as shown in the plan-view sketch (fig. 2). The pickups were oriented with their responsive axes perpendicular to the wing. These pickups and the associated multiple-channel amplifying and recording equipment were furnished by courtesy of the Glenn L. Martin Company. A special vibrator driven by a small air turbine was installed in the fuselage. The use of the air-turbine drive was resorted to as it proved difficult to shield the field of an electric motor sufficiently to prevent disturbances in the pickups. The model was very substantially supported at a point considerably behind the center of gravity of the model. The vibrator itself was placed close to the center of gravity of the wing with its plane of rotation perpendicular to the fuselage axis. Since a single weight vibrator was used, there was thus both a vertical and a horizontal force, the latter giving rise to a somewhat unwanted chordwise motion of the wings, or "side rocking." It should be noted that the support was constructed so as to permit either restraint or freedom in rotation about the center line of the fuselage.

A set of preliminary runs was made to insure efficient operation of the equipment. It was soon established that no appreciable deflection was obtained on the inboard pickup elements. The elements near the tip of each wing and two elements giving aileron position were therefore permanently assigned to the six available channels of the amplifier system. A typical vibration record is shown in figure 3.

Considerable difficulty was experienced in identifying the main torsional frequency, and it also proved to be rather much higher than the value prescribed by Vought-Sikorsky Aircraft, namely, 1575 cpm instead of a reported value of about 1250 cpm. This difficulty, which is typical of the difficulty often encountered in vibration tests, was caused by the presence of other responses very near the torsional.

A method used by the Laboratory on several other occasions proved successful in overcoming the trouble. By attaching a relatively large concentrated mass at the torsion axis near the wing tip, a spectral resolution was obtained by pushing the interfering responses out of the range. By resorting to various means of displacing or suppressing one or more responses, the various modes were successively identified. The chordwise bending occurred at 1250 cpm and a nonsymmetrical bending mode at 1350 cpm. For instance, the chordwise bending could thus be suppressed by attaching strings to the wing tips in the chordwise direction. (See fig. 4.) The frequency and phase effects of mass added at wing tips are shown in figures 5(a) and (b). Measured damping parameters for the wing in bending, left and right aileron deflections, respectively, are shown in figures 6(a), (b), and (c).

RESULTS OF PRELIMINARY TESTS ON FLUTTER PARAMETERS

OF THE SB2U FLUTTER MODEL

Symmetrical bending, cpm	670
Nonsymmetrical bending, cpm	1350
Chordwise bending, cpm	1250
Torsion, cpm	1575
Damping of wing in bending	g_h = 0.05
Damping of left aileron, approximately	g_β = 0.5
Damping of right aileron, approximately	g_β = 0.5

As a result of the higher than expected value of torsional frequency, the calculated flutter speed of the model increased to 150 miles per hour. It is also noted that the aileron damping was undesirably high.

MAIN TESTS

These tests were run to study the effect of the air stream on the magnitude of the various responses, in particular near the flutter speed. Tests were run in the 16-foot tunnel at speeds of 0, 50, 75, 100, 110, 120, 130, and 140 miles per hour. At each speed, the frequency of the impressed force was changed throughout a range of from 500 to about 2000 cpm. A larger vibrator mass was employed for the lower frequencies to keep the force more nearly constant.

The test results are shown in a series of graphs showing the responses versus frequency for the eight airspeeds. These graphs are given in figures 7 to 36, inclusive. It should be noted that, in these figures, the amplitude refers to a given mass of the vibrator and that the impressed force thus increases as the square of the frequency. The pickups are designated by numbers corresponding to those of the location drawing in figure 2. Records from only the four elements numbered 6 and 7 on the left wing and 9 and 23 on the right wing were employed in these figures. The results of the main tests may readily be visualized in the perspective photographs (a), (b), (c), and (d), in figure 37. In these photographs, the strips are for successively higher airspeeds toward the rear. Because of the excessive damping present, the records of the two aileron-position recorders were not plotted.

The tests were discontinued at 140 miles per hour, which speed was in excess of the originally expected value of 120 miles per hour given in references 2 and 3. The skin buckled in a disturbing manner, and it was feared that destruction might result from a local skin failure. In fact, this buckling also occurred at about 125 miles per hour. However, in each case the skin stiffener snapped back in position when lightly pushed.

DISCUSSION

The most noteworthy feature of the test results is the small change of amplitude as the airspeed is increased. This very gradual approach to flutter is somewhat unexpected and may not be typical of modern construction.

Evidently a complex structure may exhibit local frequencies and energy-absorbing qualities, which results in a rather irregular response pattern of the type recorded. A condition of near-flutter may thus be suppressed by the existence of high internal damping at the particular frequency involved.

Until more evidence is available, either from model tests or from flight, it is not possible to recommend a specific technique for flutter testing in flight.

RECOMMENDATIONS

It is recommended that the torsional stiffness of the wing be decreased to give a flutter speed near 120 miles per hour so as to avoid the observed skin buckling, and that a special test be run to observe the flutter speed and also, if possible, the appearance of the response peak below this speed.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 17, 1943.

REFERENCES

1. Loring, S. J., and Lawrence, S. G.: Study of SB2U Wing Flutter. Rep. No. 4845, Vought-Sikorsky Aircraft, Feb. 19, 1940.

2. Sandgren, F. B.: Flutter Model - 1/4 Scale Model of SB2U-2 Wing - Design Data. Rep. No. 5744, Vought-Sikorsky Aircraft, Oct. 1, 1941.

3. Loring, S. J., and Sandgren, F. B.: Dynamic Tests of 1/4 Scale Flutter Model of SB2U-1,2 Wing. Rep. No. 5832, Vought-Sikorsky Aircraft, June 19, 1942.

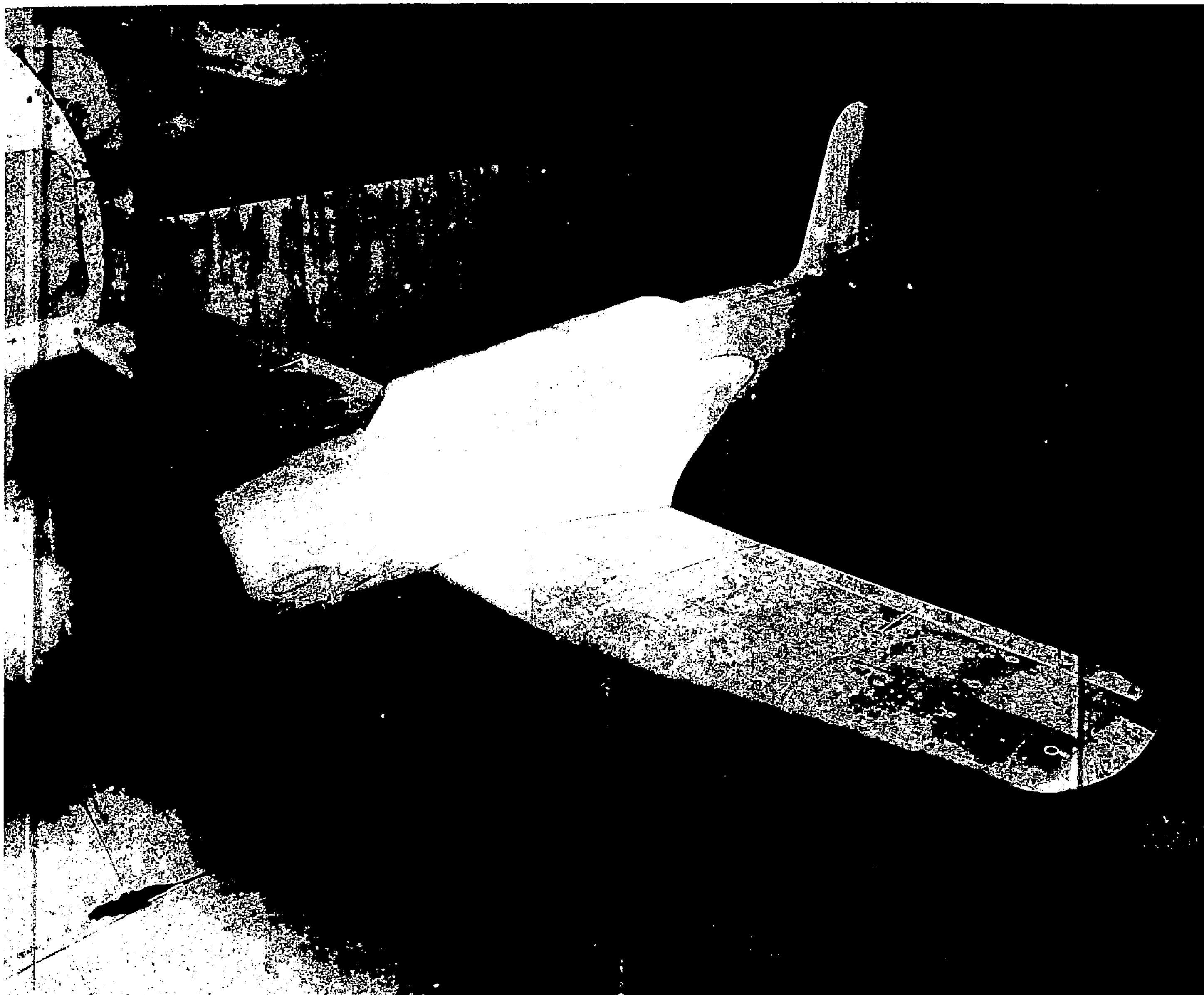


Figure 1a.

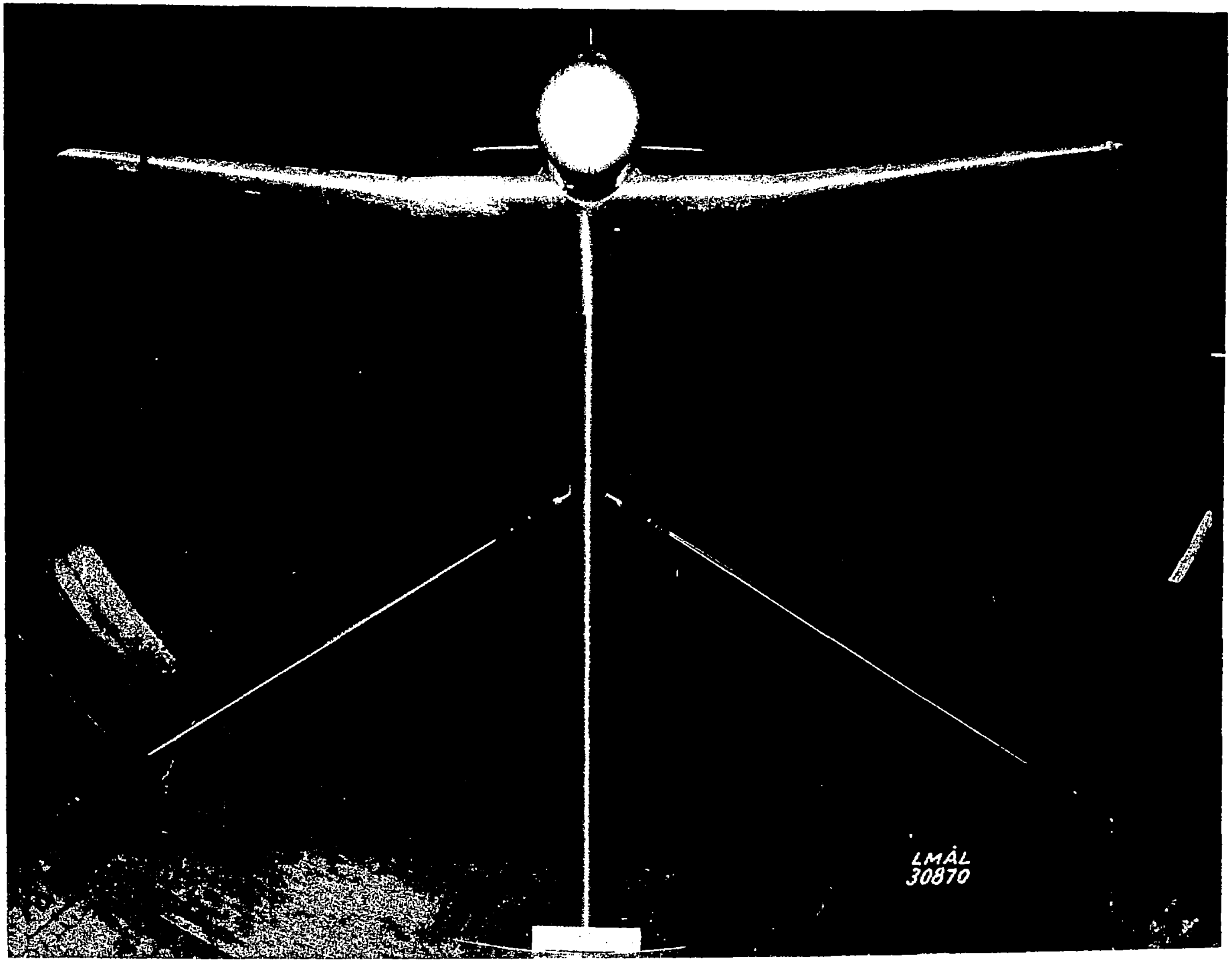
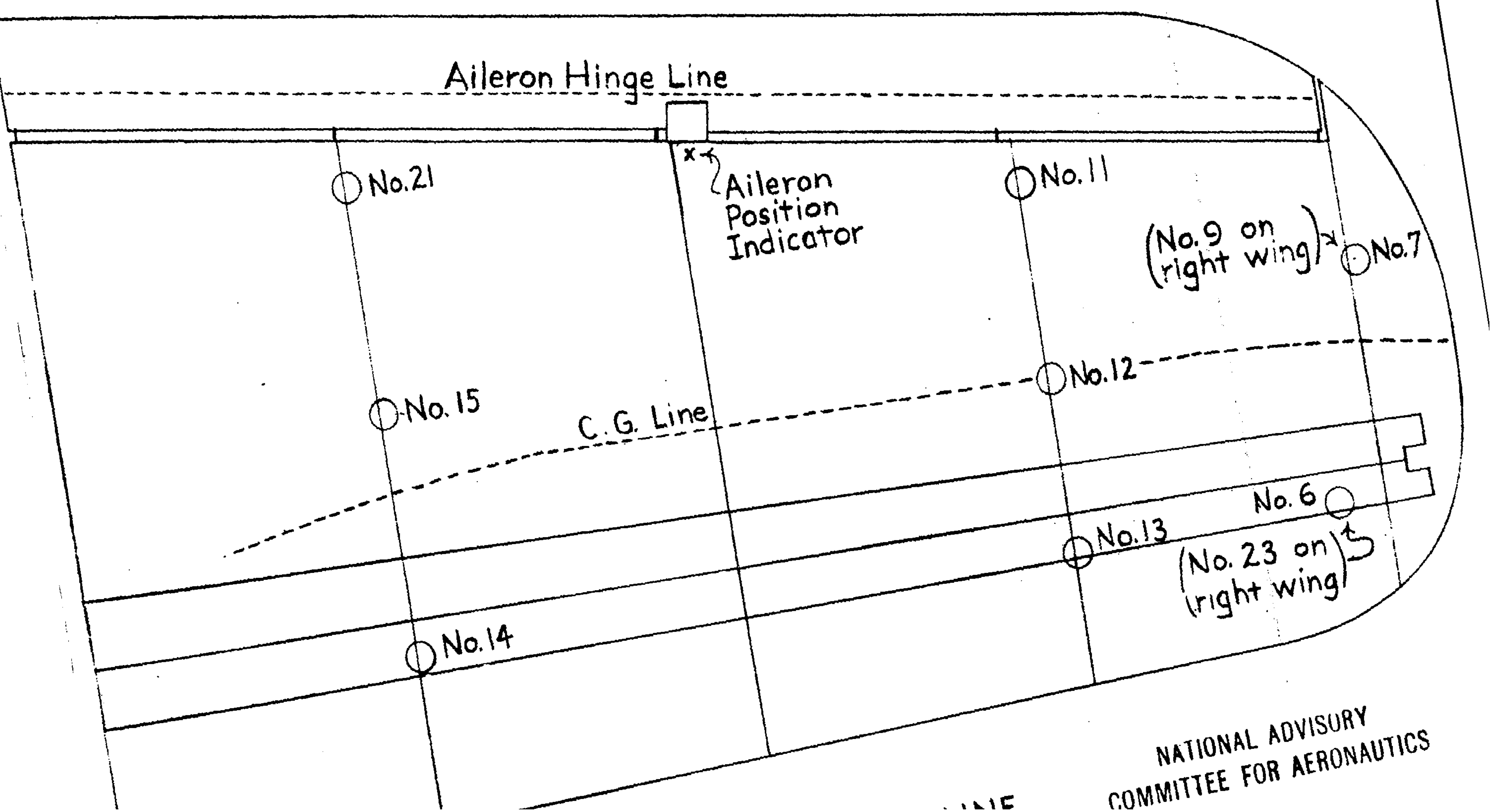


Figure 1c.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

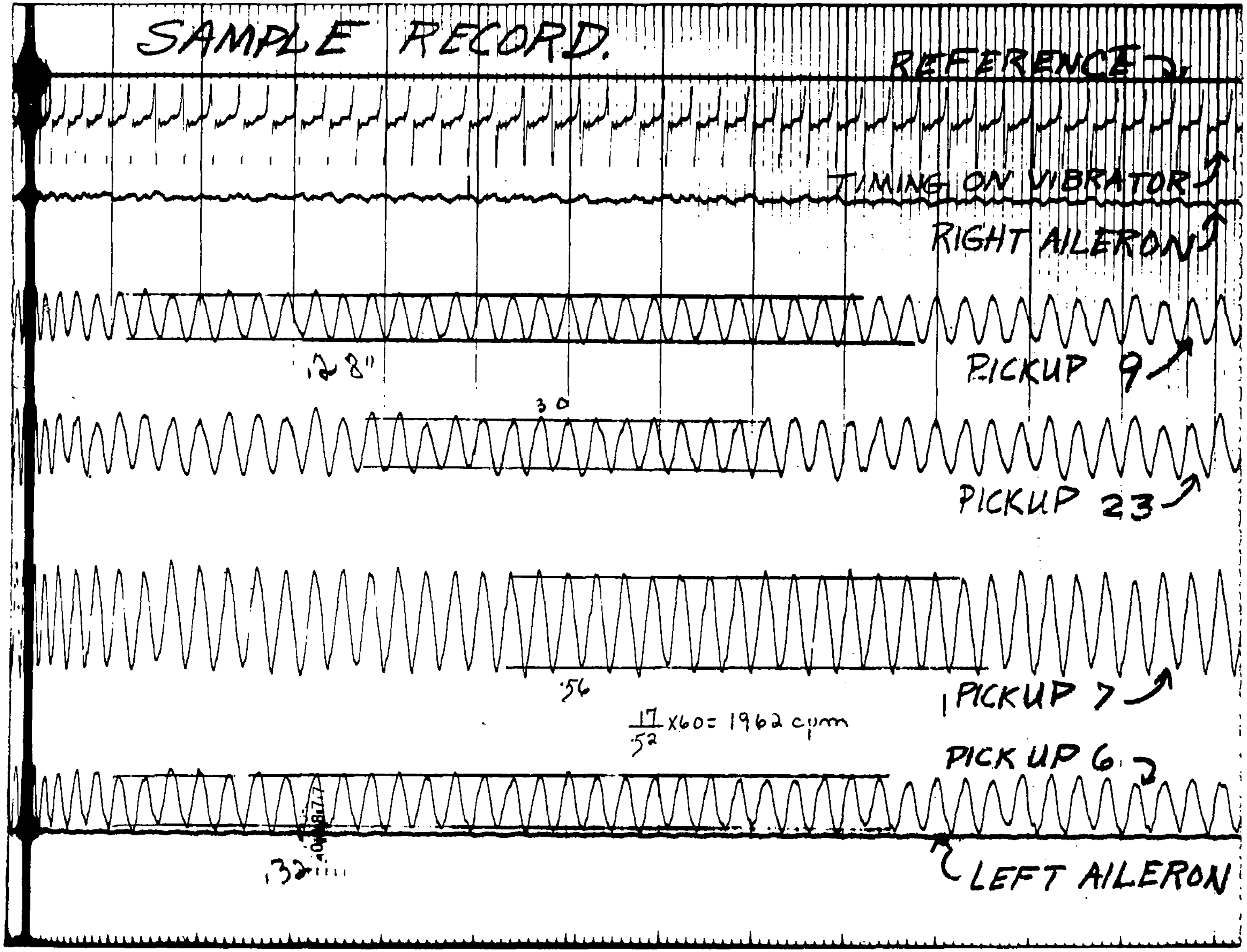

SAMPLE RECORD.
REFERENCE
TIMING ON VIBRATOR
RIGHT AILERON
.128"
PICKUP 9
.30
PICKUP 23
.56
PICKUP 7
$\frac{17}{.52}$ x60 = 1962 cpm
PICK UP 6
.32
LEFT AILERON

FIGURE 3

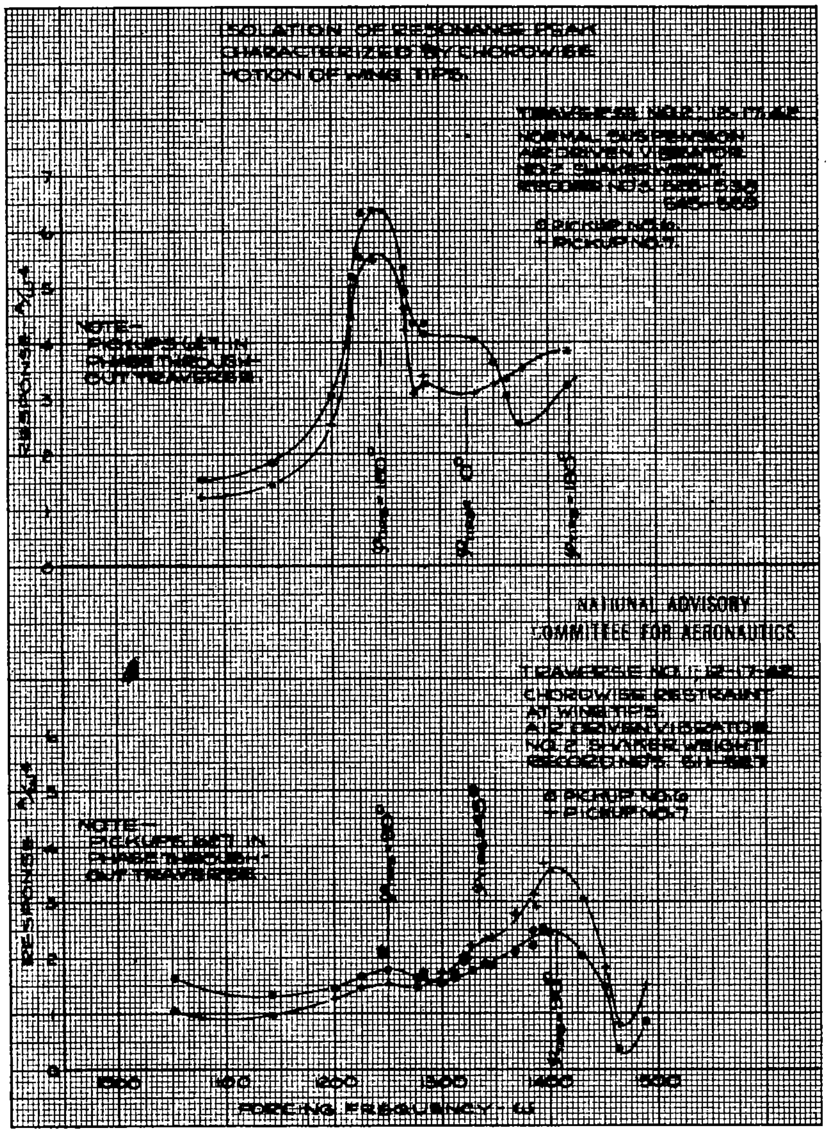


FIGURE 4

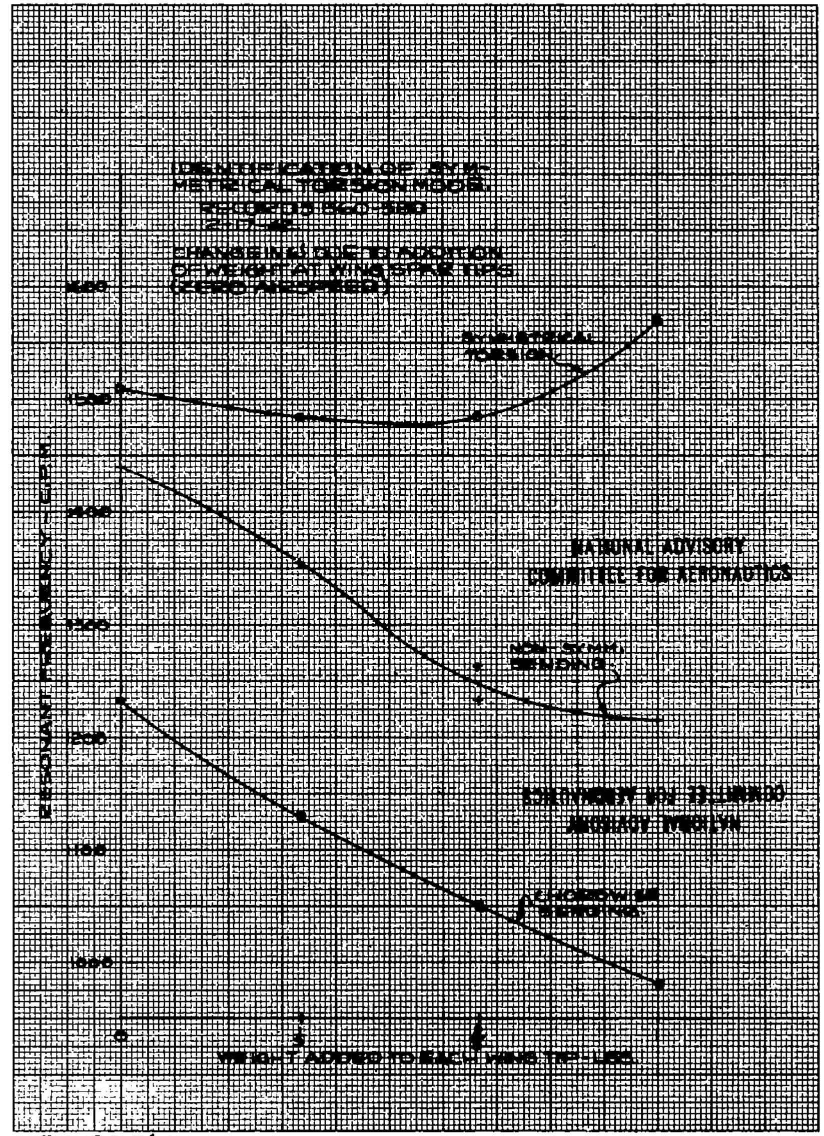


FIGURE 5(a)

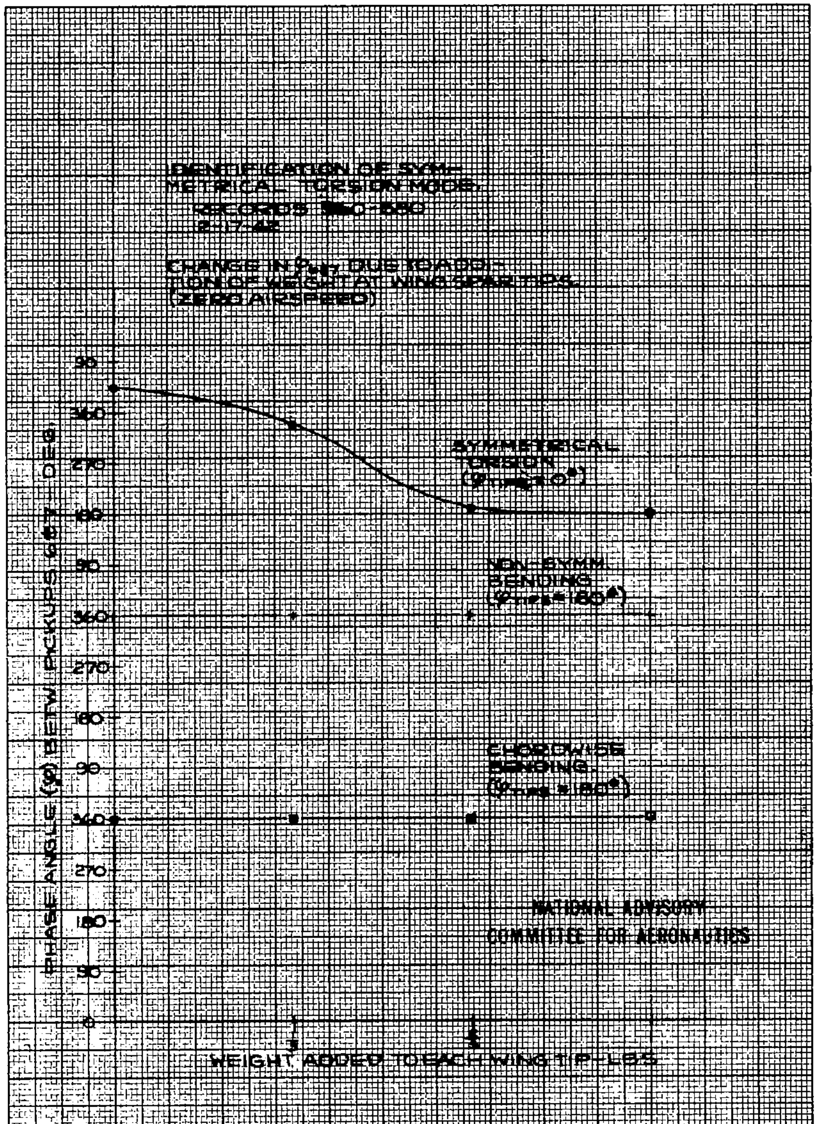


FIGURE 5-(.b)

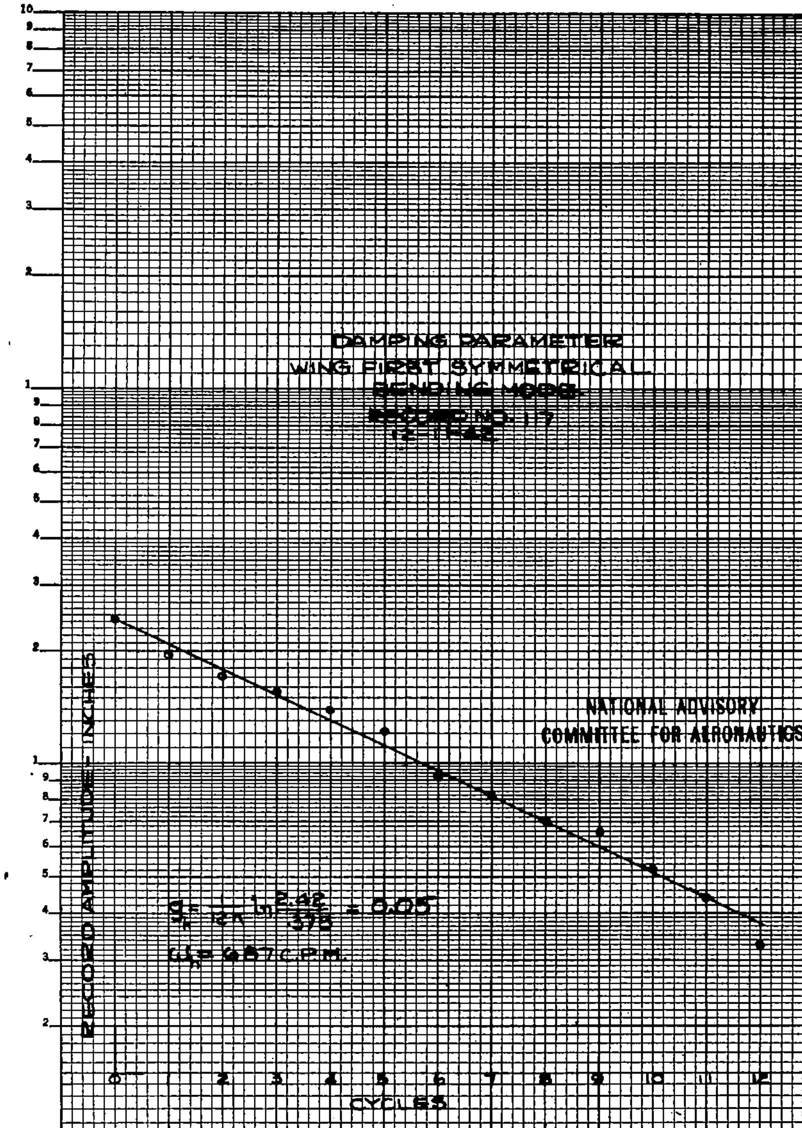


FIGURE 6-(a)

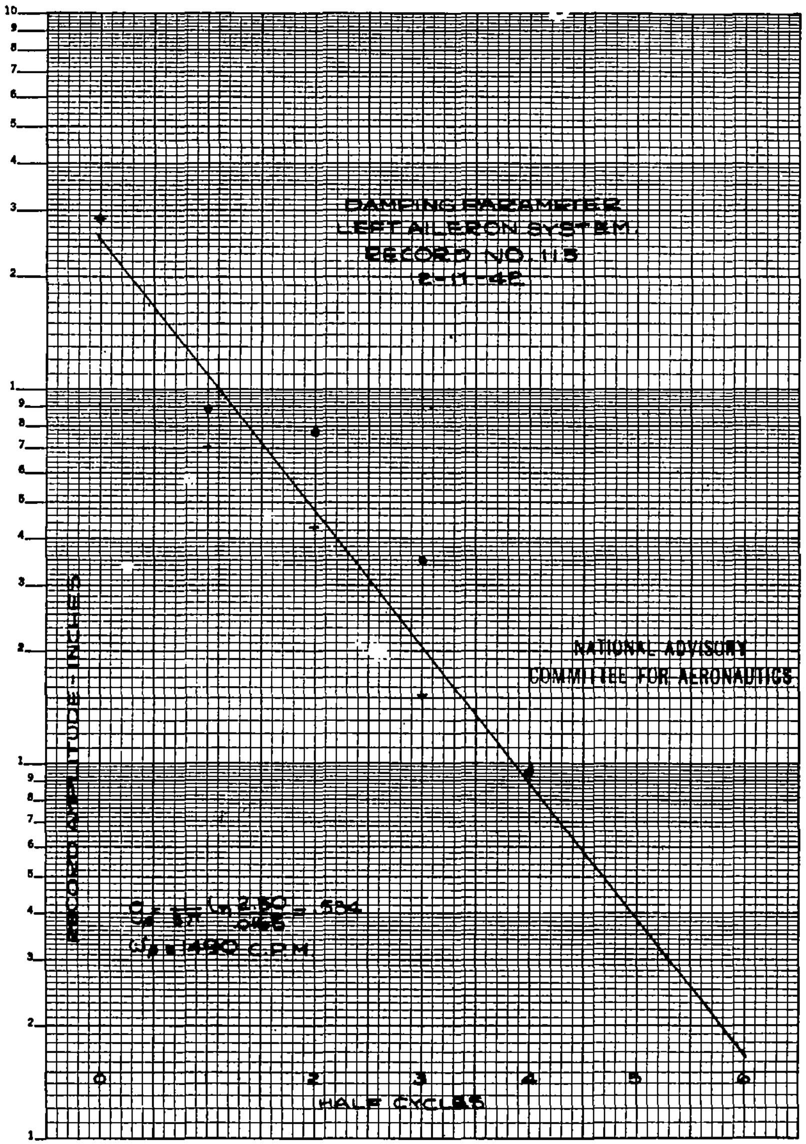


FIGURE 6-(b)

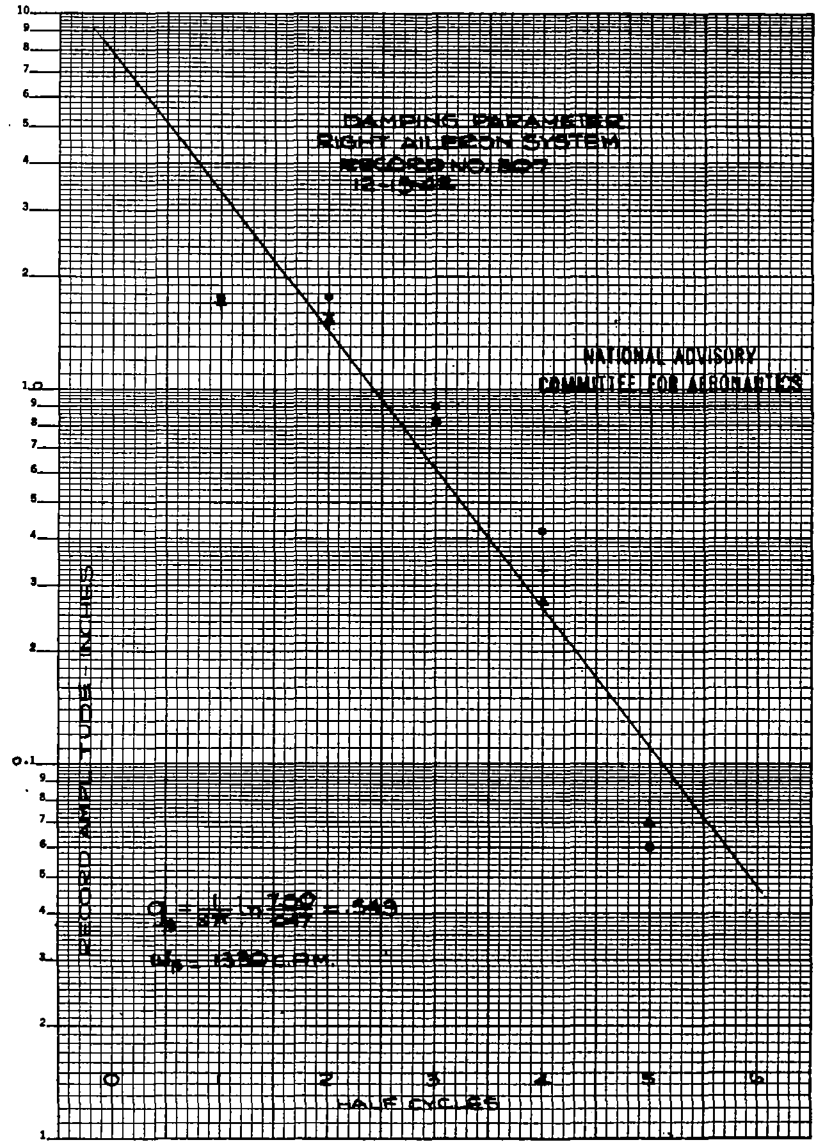
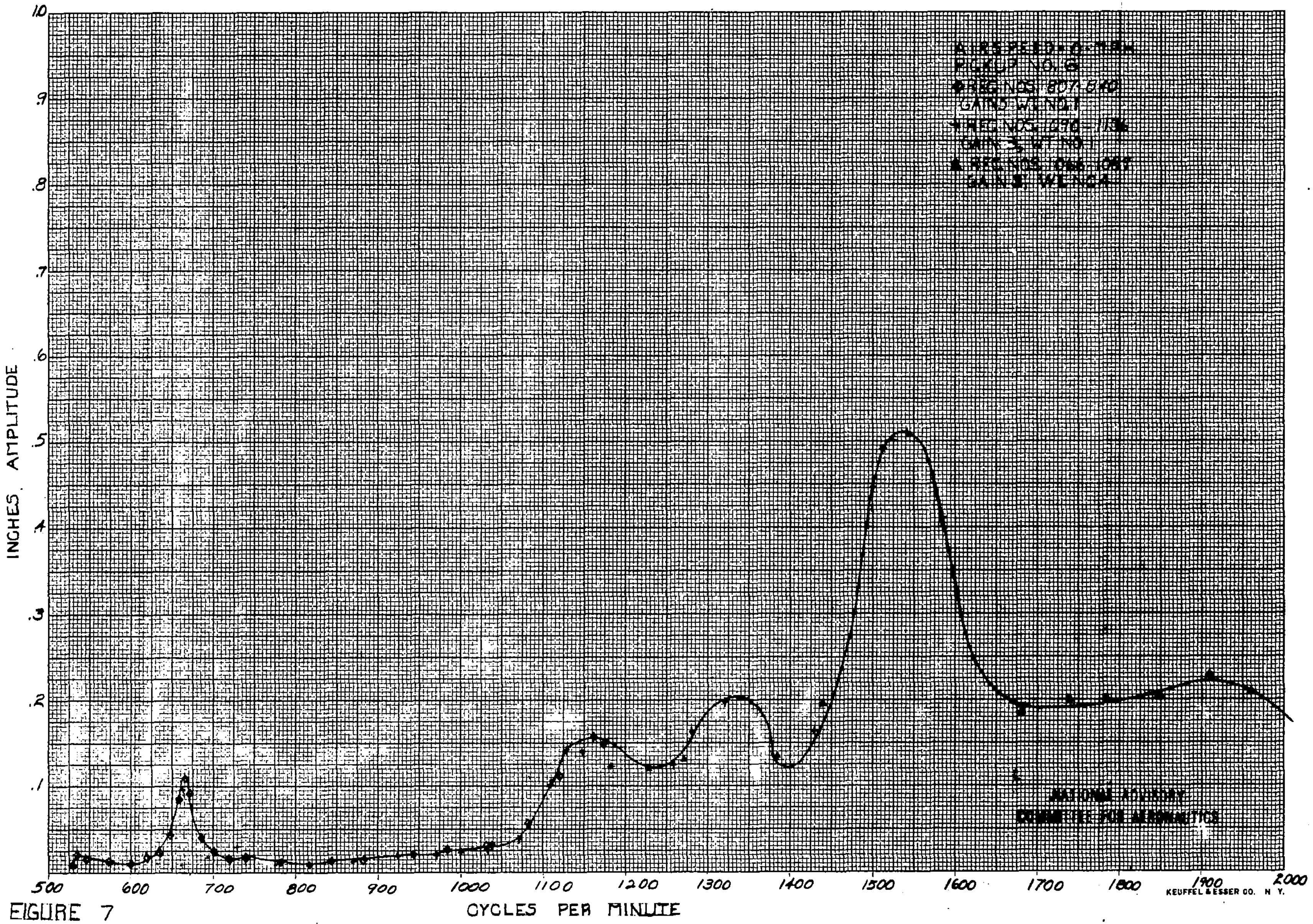


FIGURE 6-(c)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.4
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.8
.9
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700
800
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1100
1200
1300
1400
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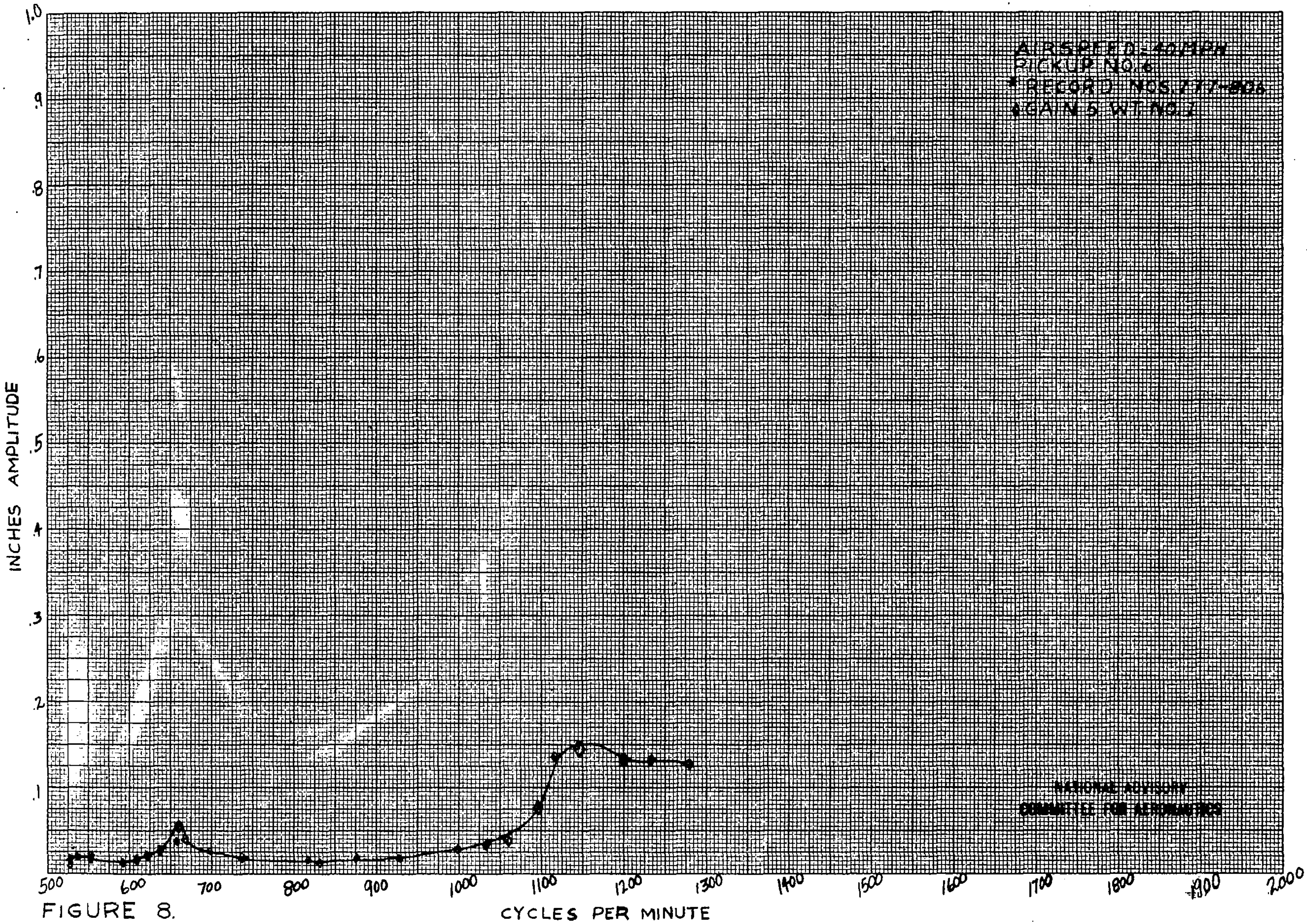
1600
1700
1800
1900
2000
CYCLES PER MINUTE
PICKUP NO. 6
REC. NOS. 807-840
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
KEUFFEL & ESSER CO. N. Y.

FIGURE 7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COMMITTEE FOR AERONAUTICS
INCHES AMPLITUDE
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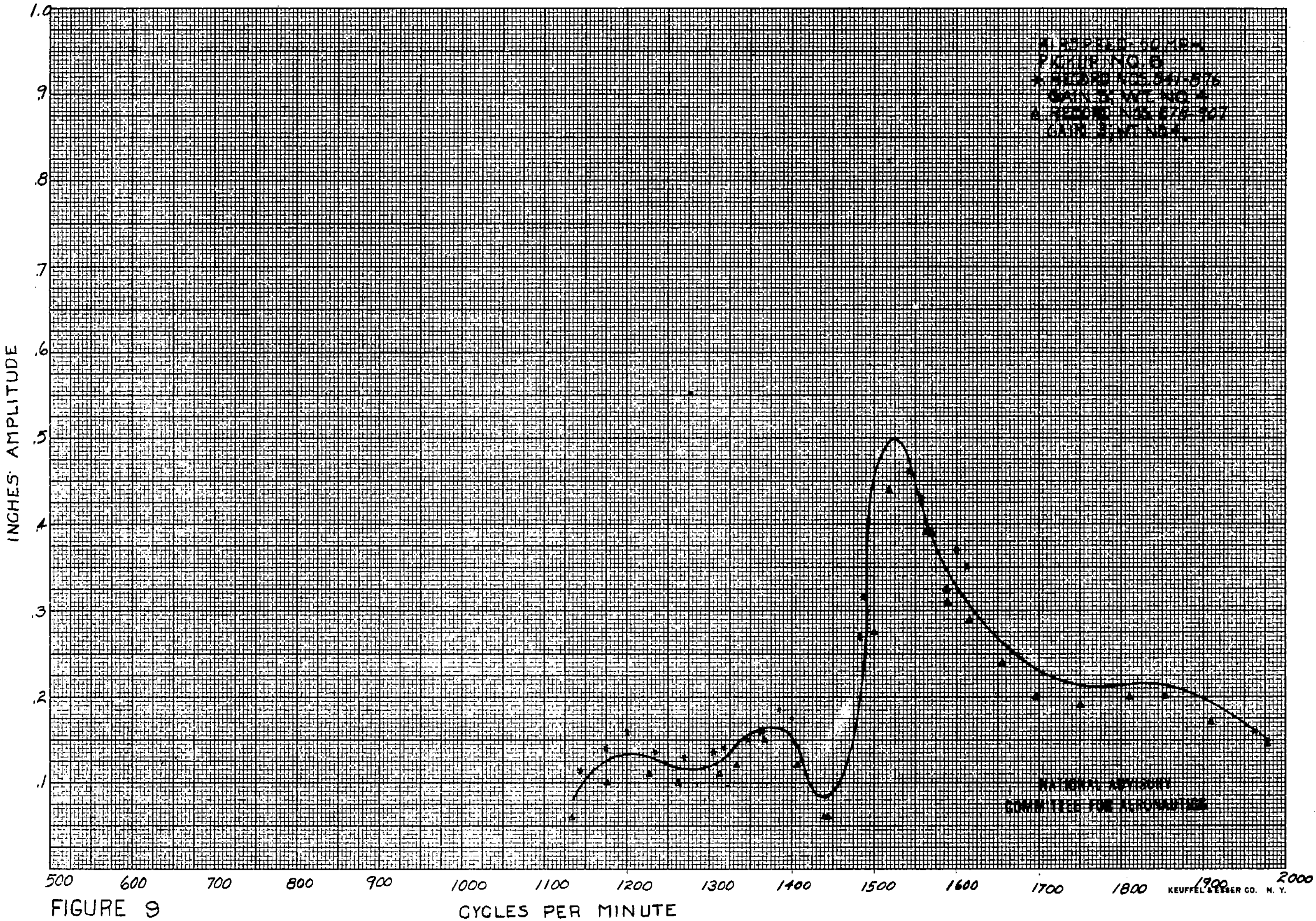
CYCLES PER MINUTE

FIGURE 8.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800
900
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NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
KEUFFEL & ESSER CO. N. Y.
CYCLES PER MINUTE

FIGURE 9

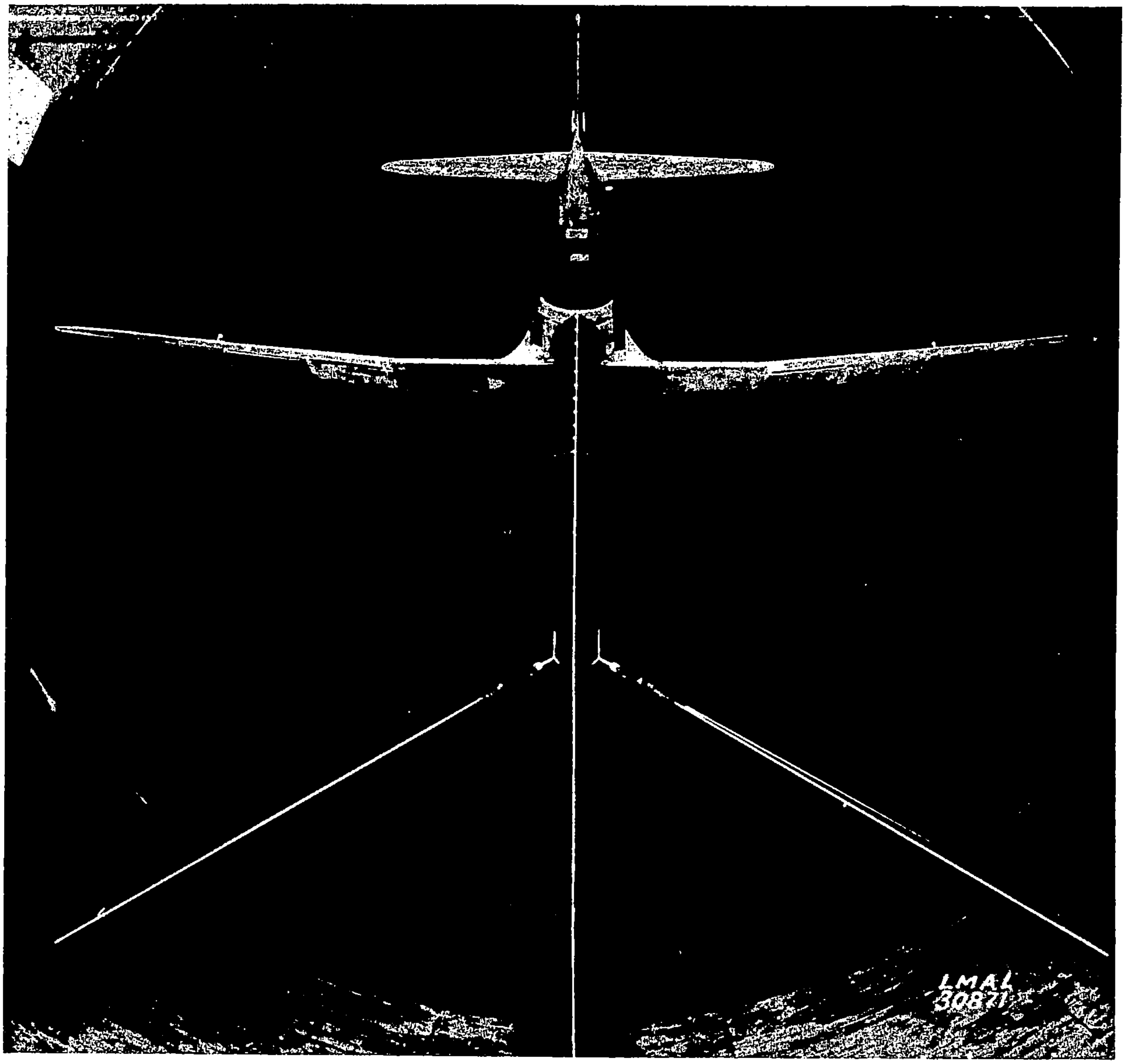
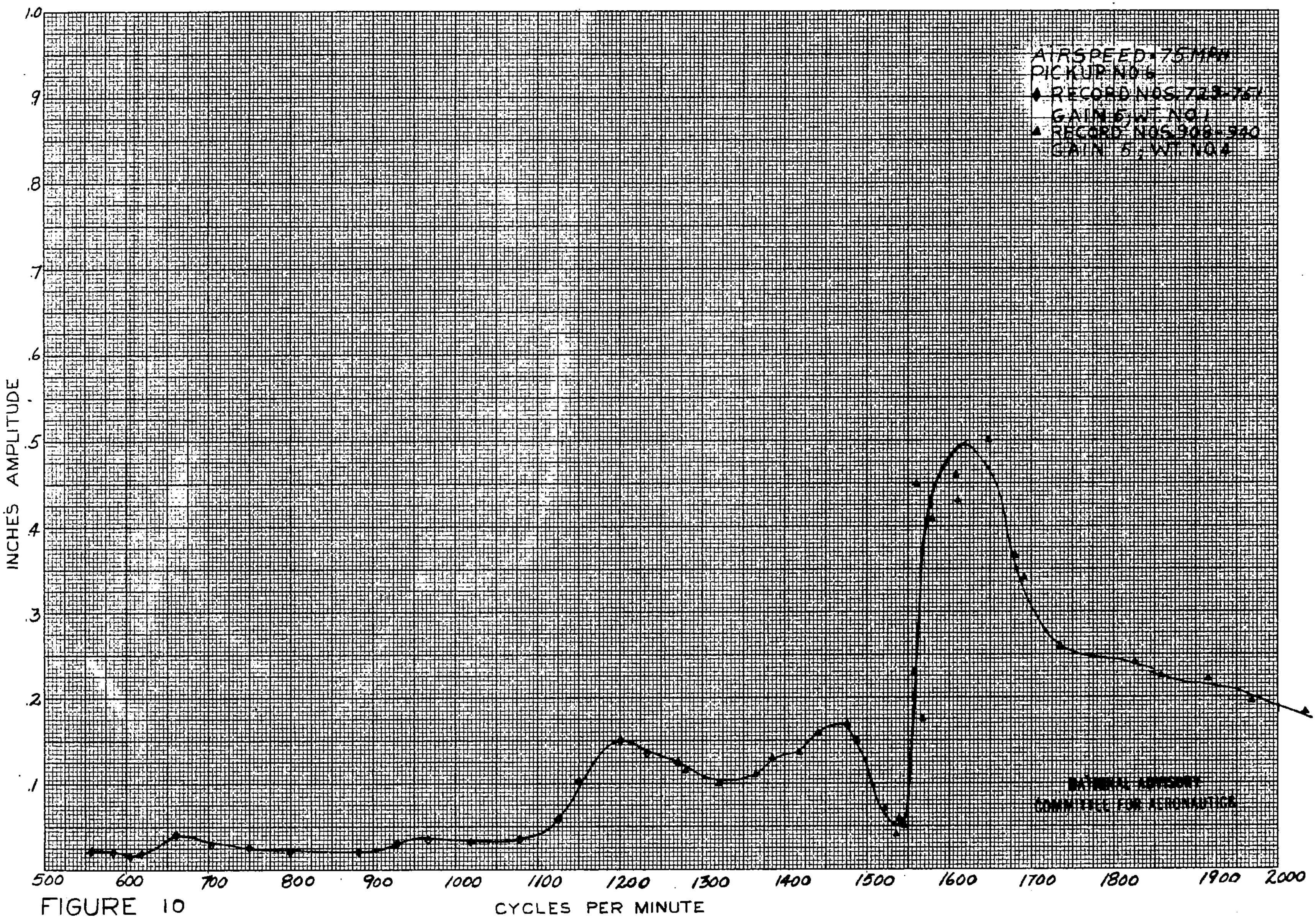


Figure 1b.


AIRSPEED = 75 MPH
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GAIN 6, WT. NO 1
RECORD NOS. 908-940
GAIN 6; WT. NO 4
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
INCHES AMPLITUDE
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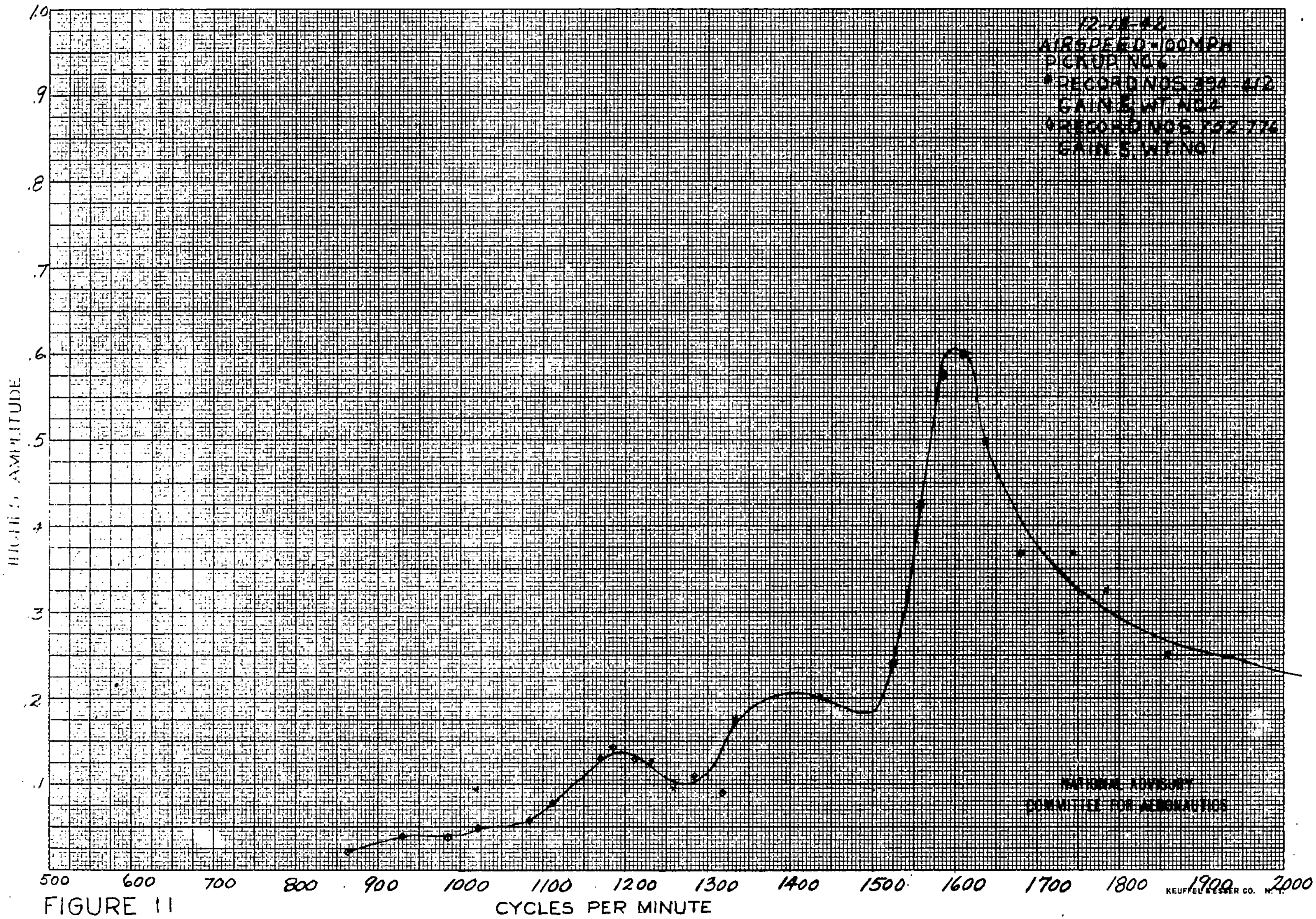
CYCLES PER MINUTE

FIGURE 10



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GAIN 5 WT. NO.4
• RECORD NOS. 722-776
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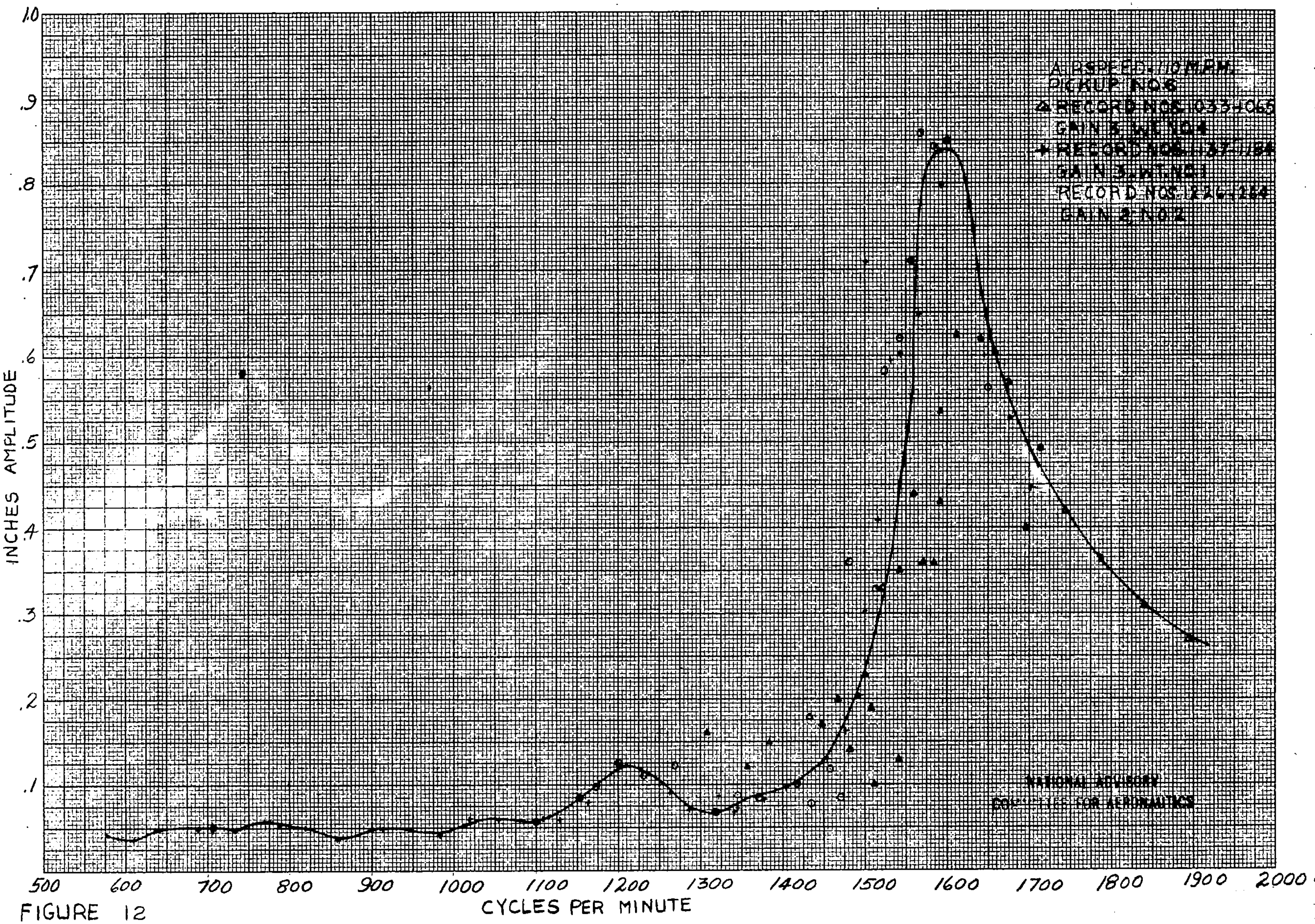
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
KEUFFEL & ESSER CO. N.Y.
CYCLES PER MINUTE

FIGURE 11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RECORD NOS.1137-1184
GAIN 3, WT. NO.1
RECORD NOS.1226-1264
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COMMITTEE FOR AERONAUTICS
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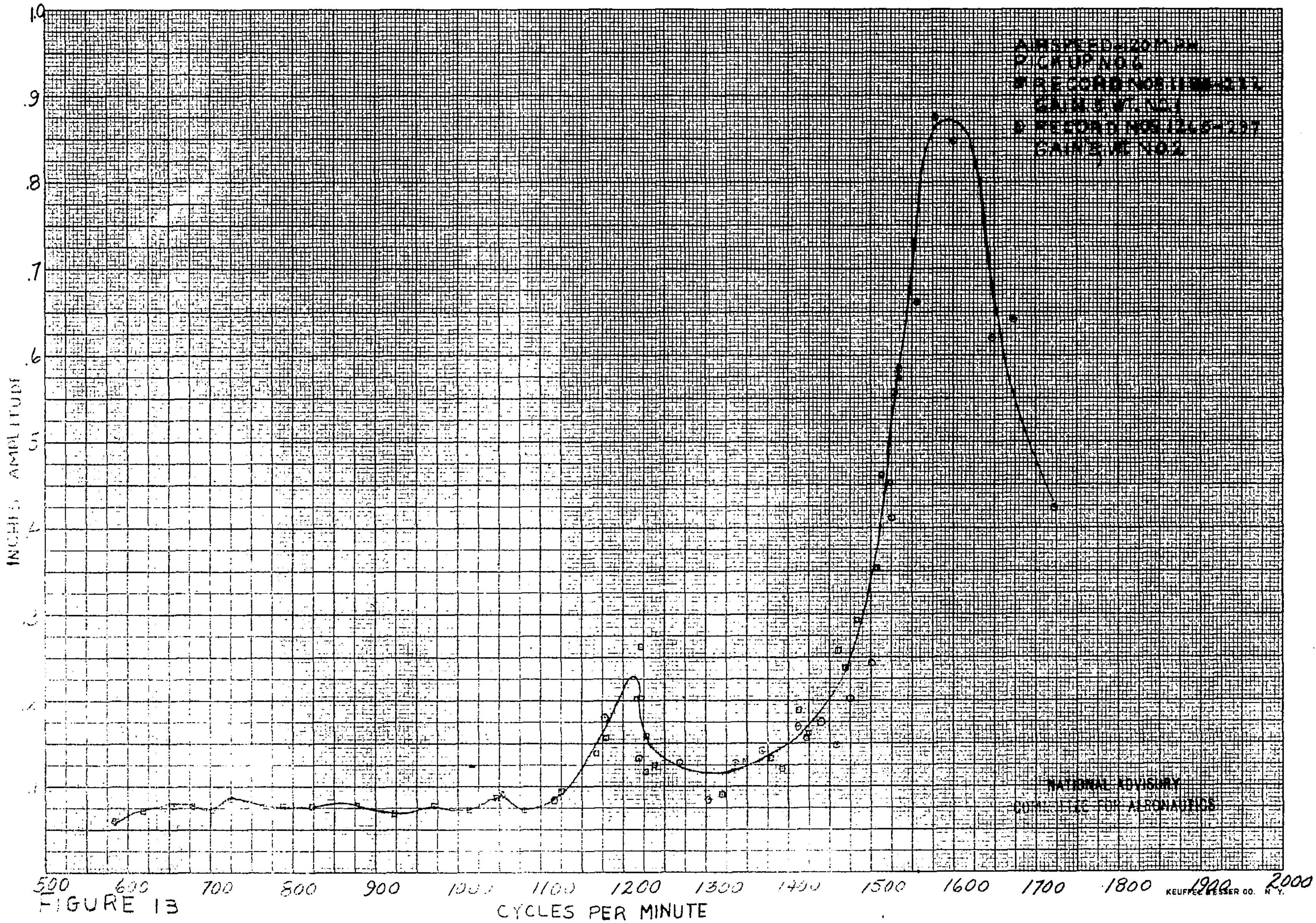
CYCLES PER MINUTE

FIGURE 12



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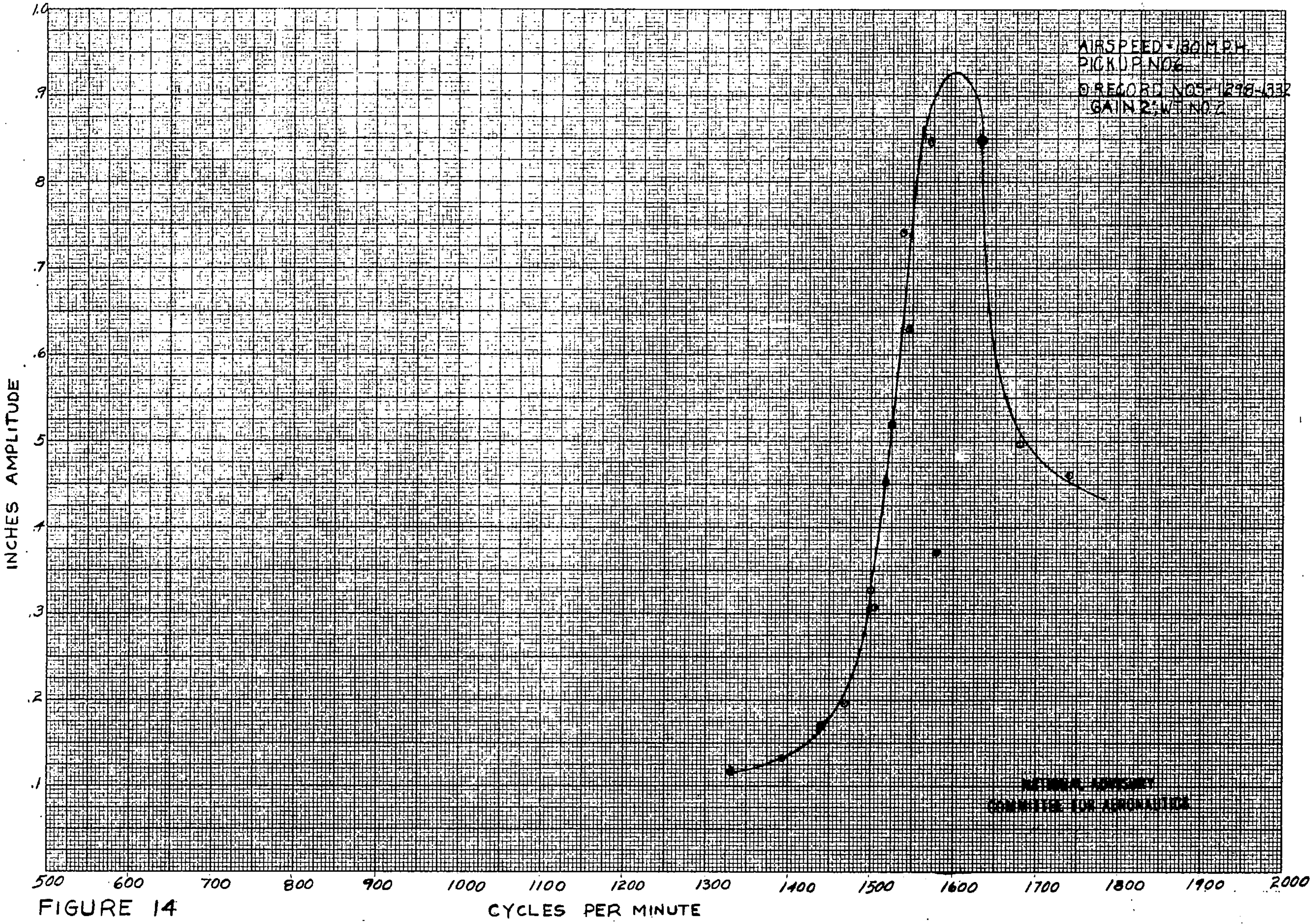
CYCLES PER MINUTE
KEUFFEL & ESSER CO. N.Y.

FIGURE 13


AIRSPEED - 180 M.P.H.
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GAIN 2; WT NO.2
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COMMITTEE FOR AERONAUTICS
INCHES AMPLITUDE
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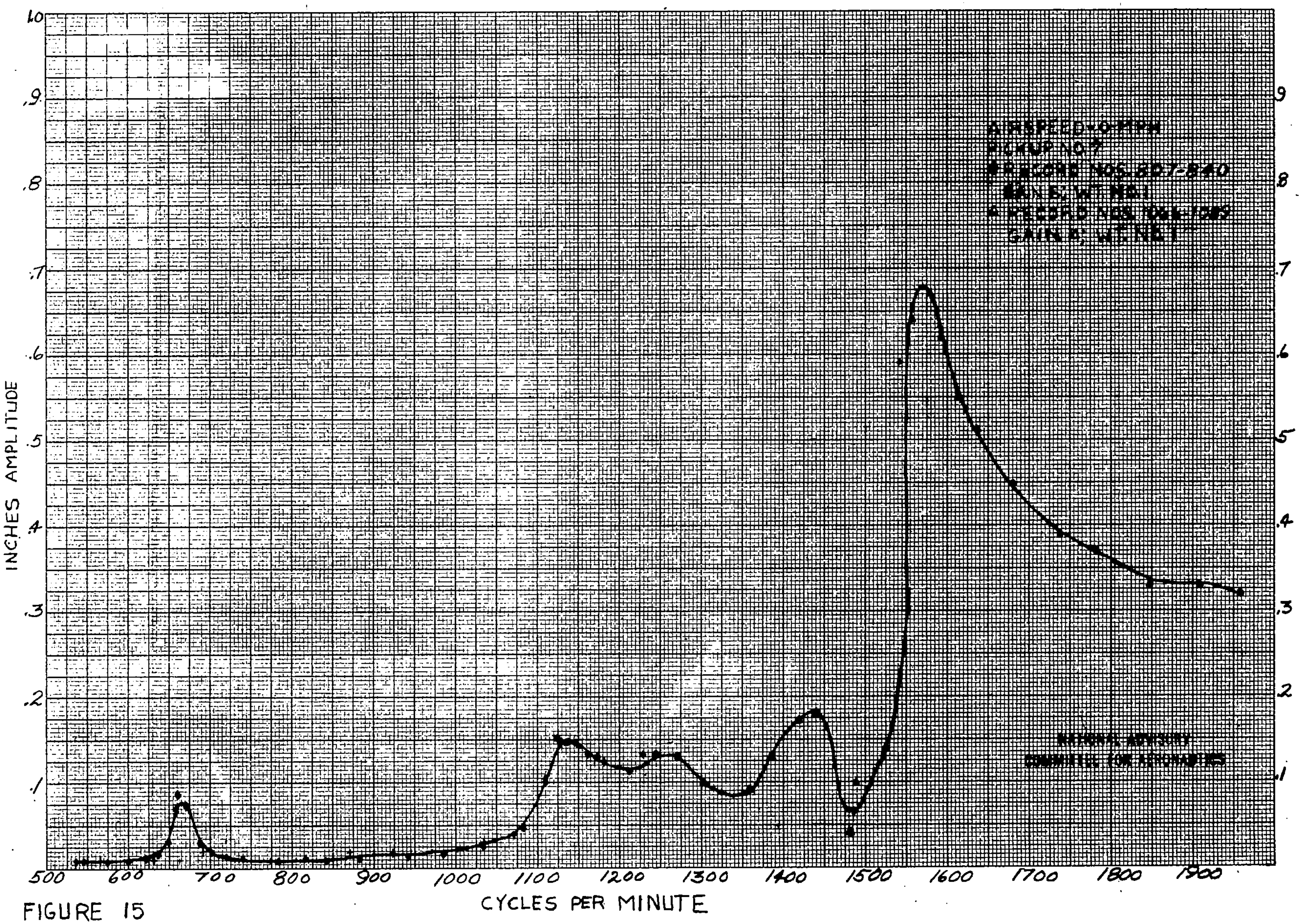
2000
CYCLES PER MINUTE

FIGURE 14



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INCHES AMPLITUDE
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CYCLES PER MINUTE
AIRSPEED-0-MPH
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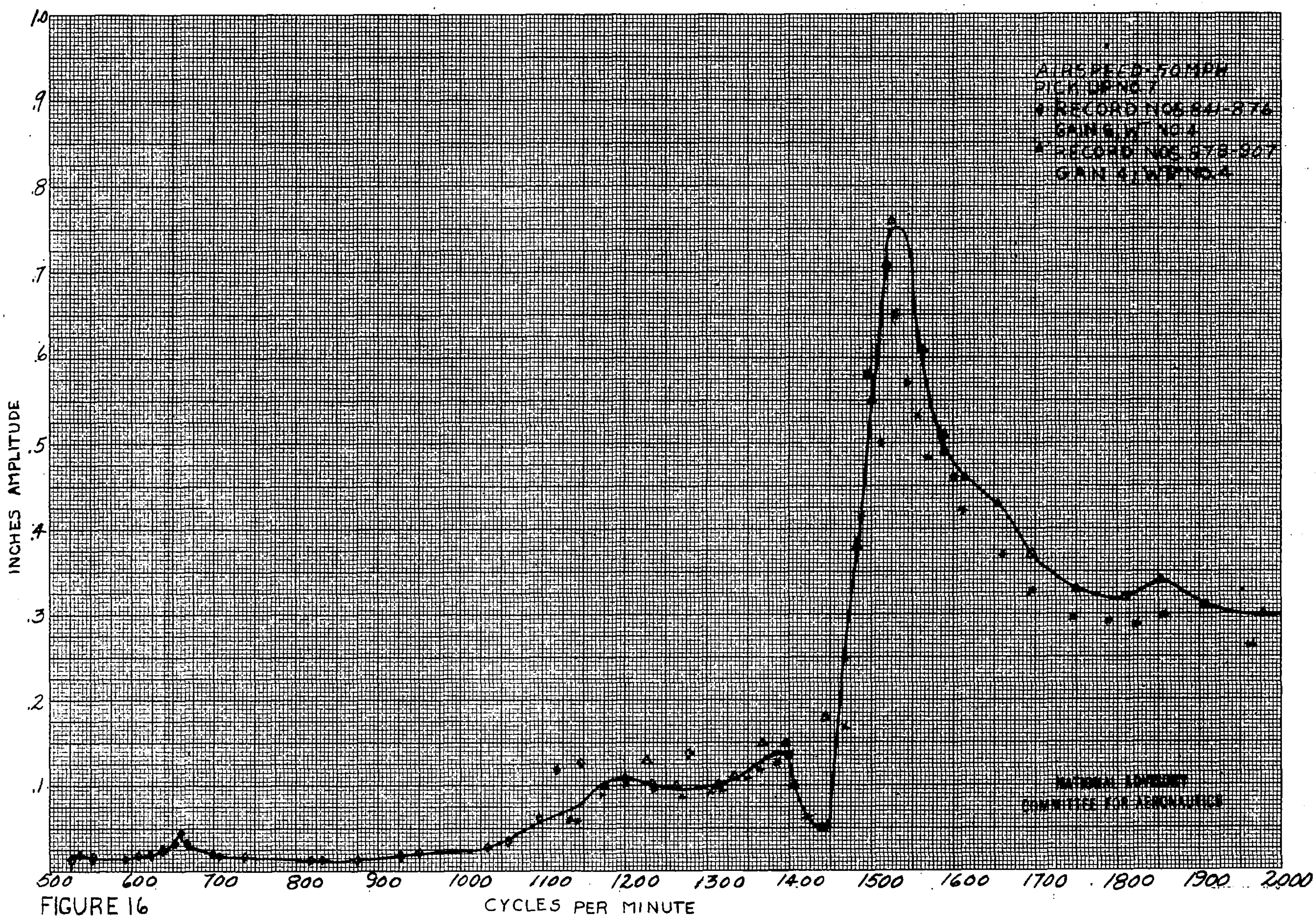
RECORD NOS. 807-840
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 15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RECORD NOS. 878-907
GAIN 4, WT NO.4
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
INCHES AMPLITUDE
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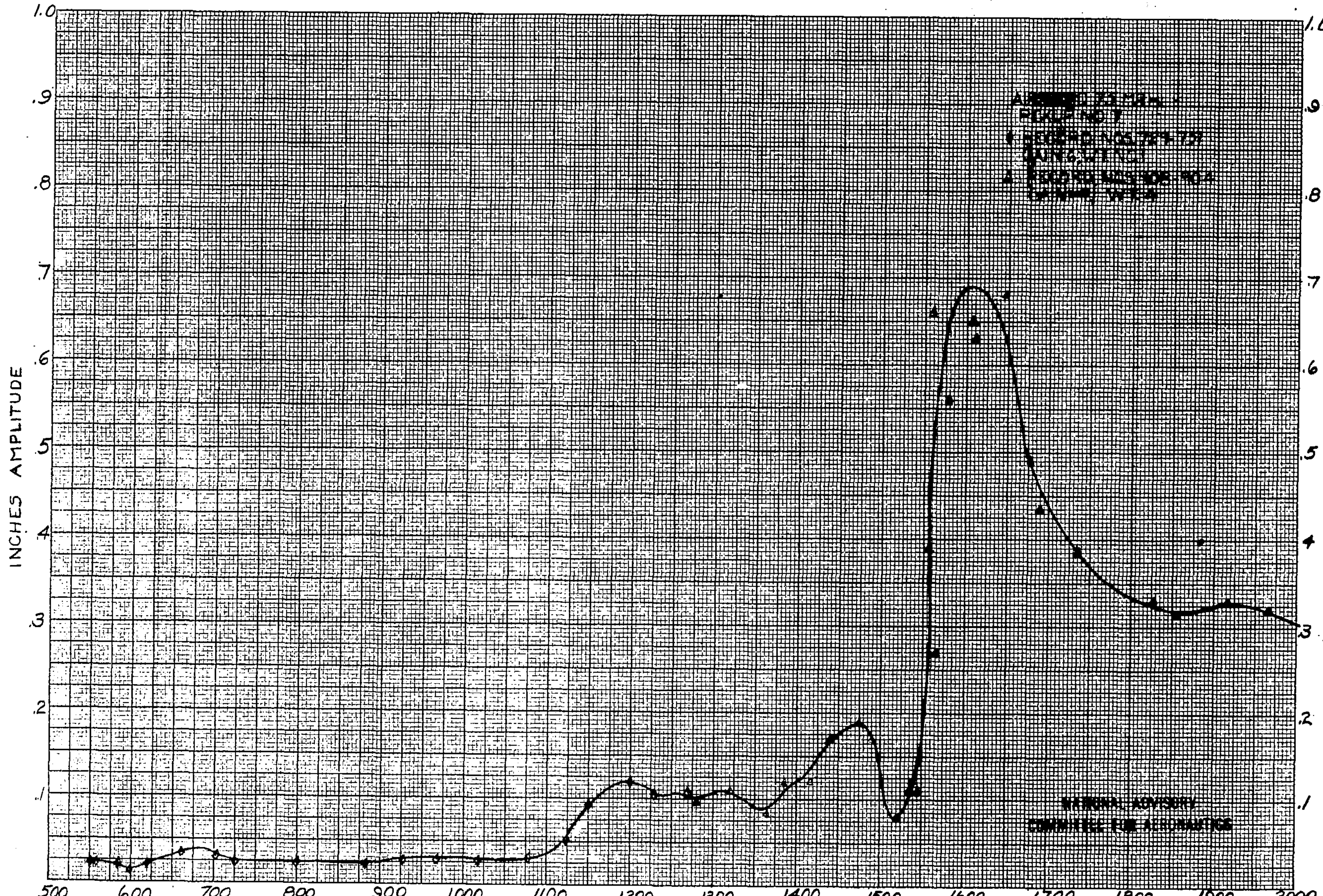
CYCLES PER MINUTE

FIGURE 16


INCHES AMPLITUDE
CYCLES PER MINUTE
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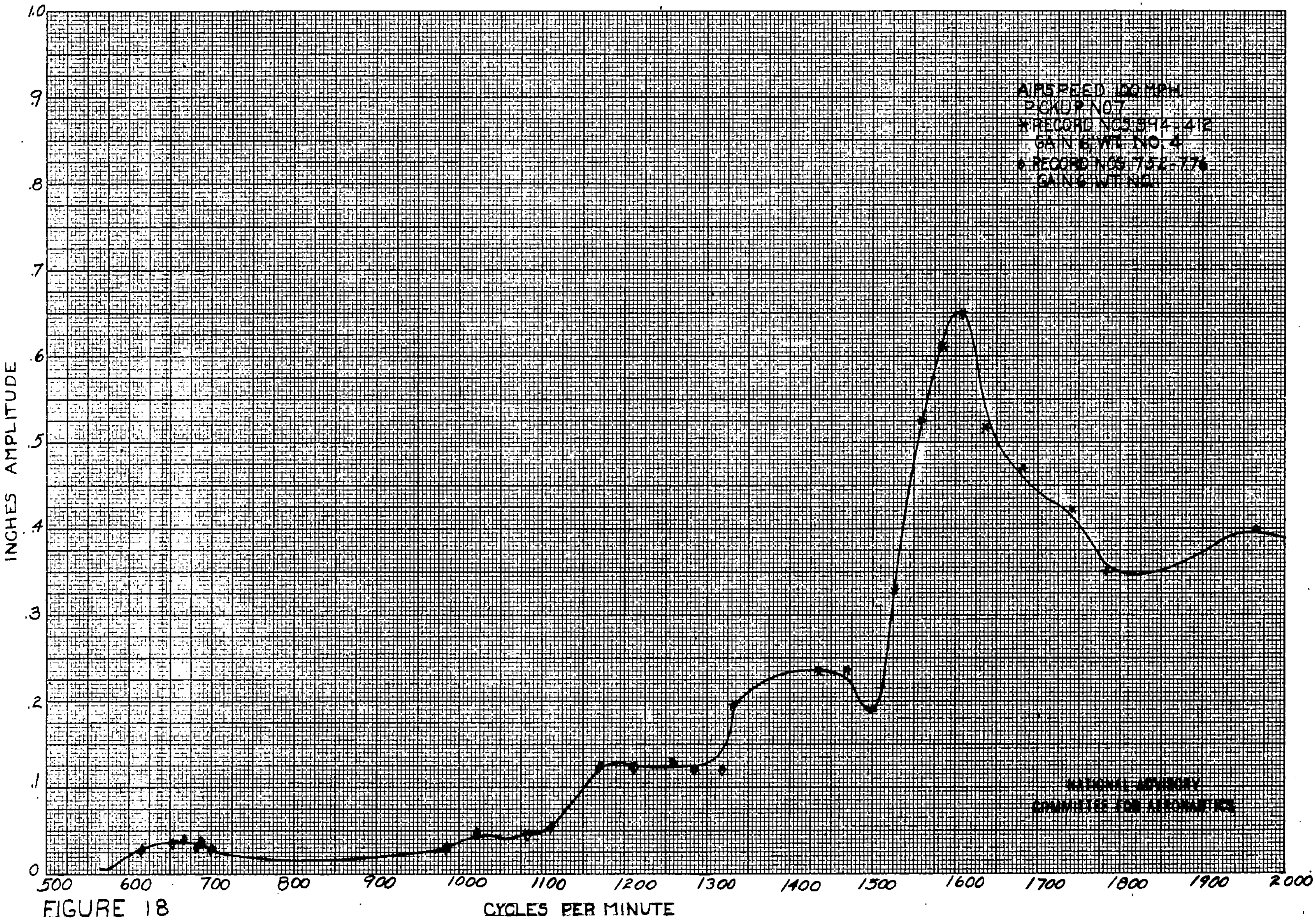
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 17


AIRSPEED 100 MPH.
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GAIN 6 WT. NO. 4
RECORD NOS 752-776
INCHES AMPLITUDE
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.3
.4
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.9
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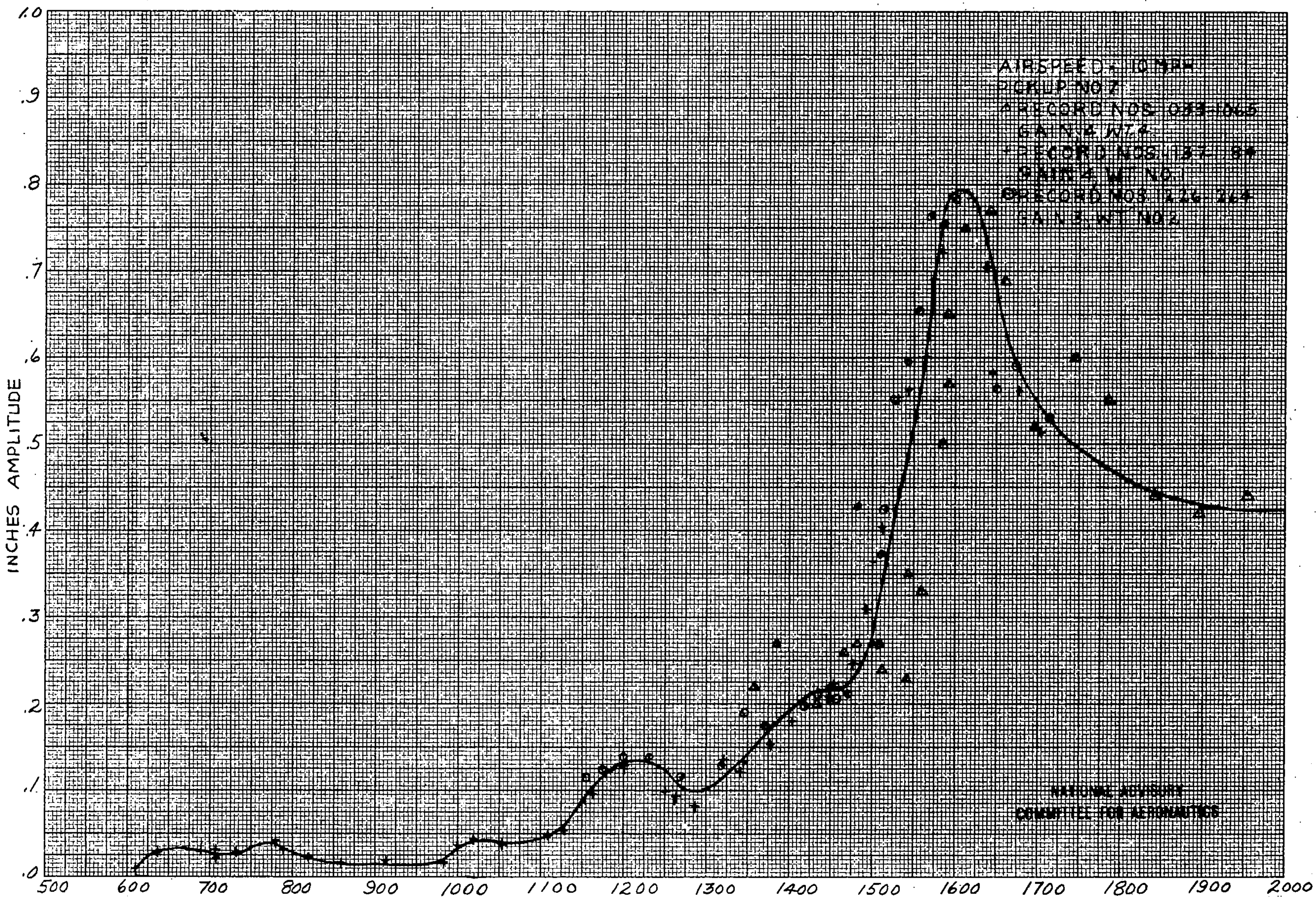
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
CYCLES PER MINUTE

FIGURE 18



AIRSPEED - 10 MPH
PICKUP NO 7
RECORD NOS
GAIN 4 WT 4
RECORD NOS
GAIN 4 WT NO 1
RECORD NOS
GAIN 3 WT NO 2
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
INCHES AMPLITUDE
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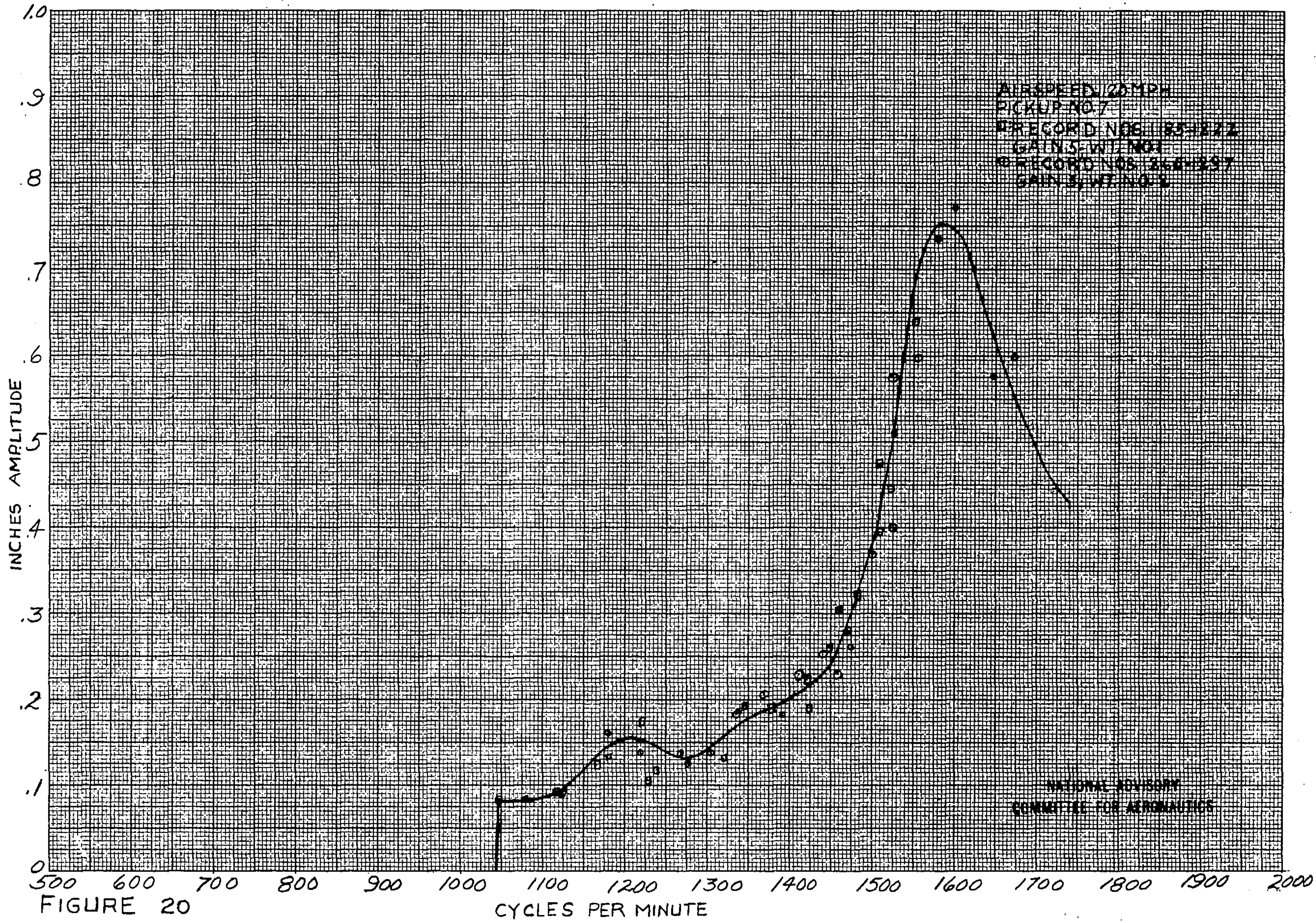
2000
CYCLES PER MINUTE

FIGURE 19



AIRSPEED 20 MPH
PICKUP NO. 7
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
INCHES AMPLITUDE
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.4
.5
.6
.7
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1.0
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1000
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1200
1300
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1700
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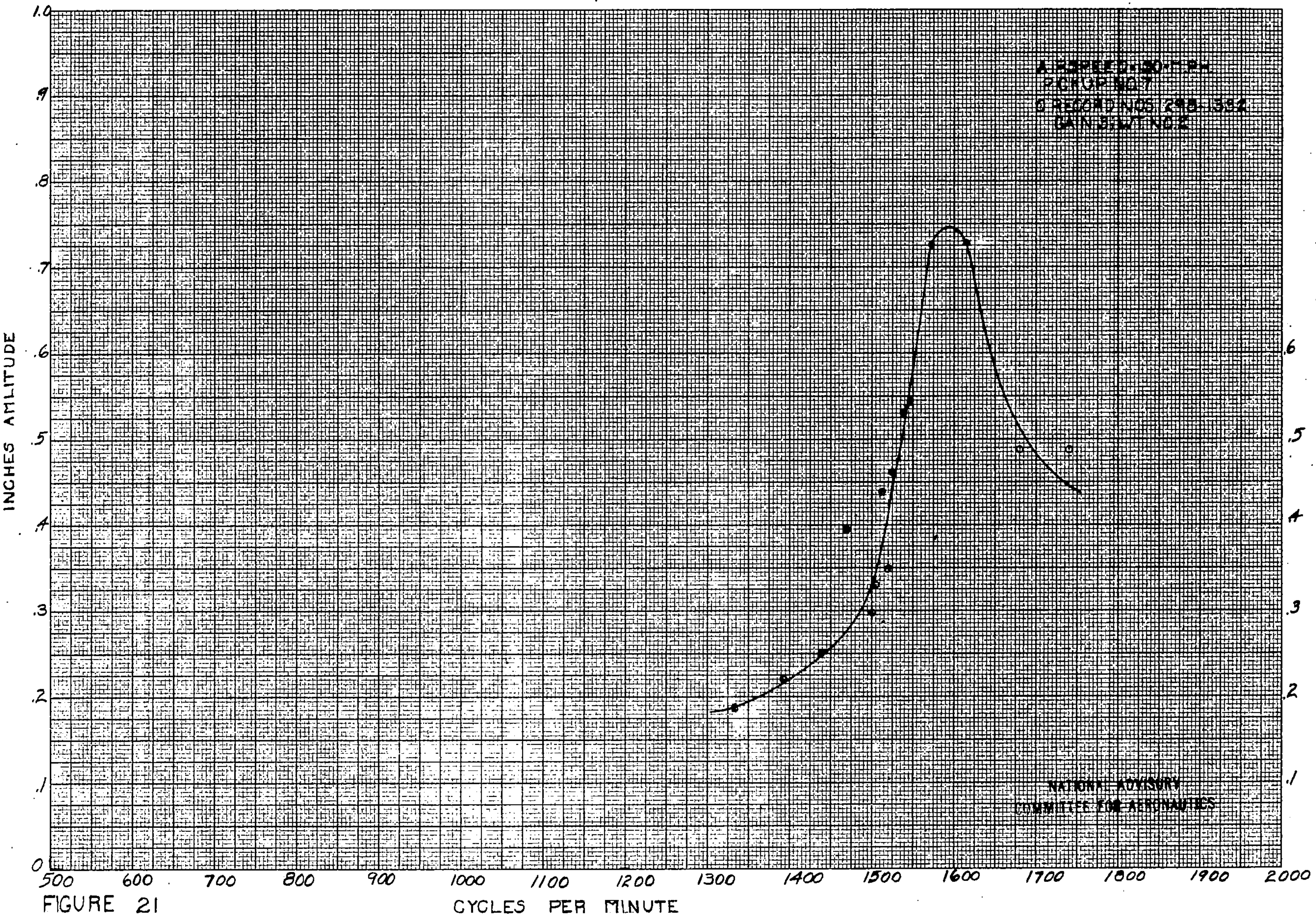
1900
2000
CYCLES PER MINUTE

FIGURE 20



INCHES AMLITUDE
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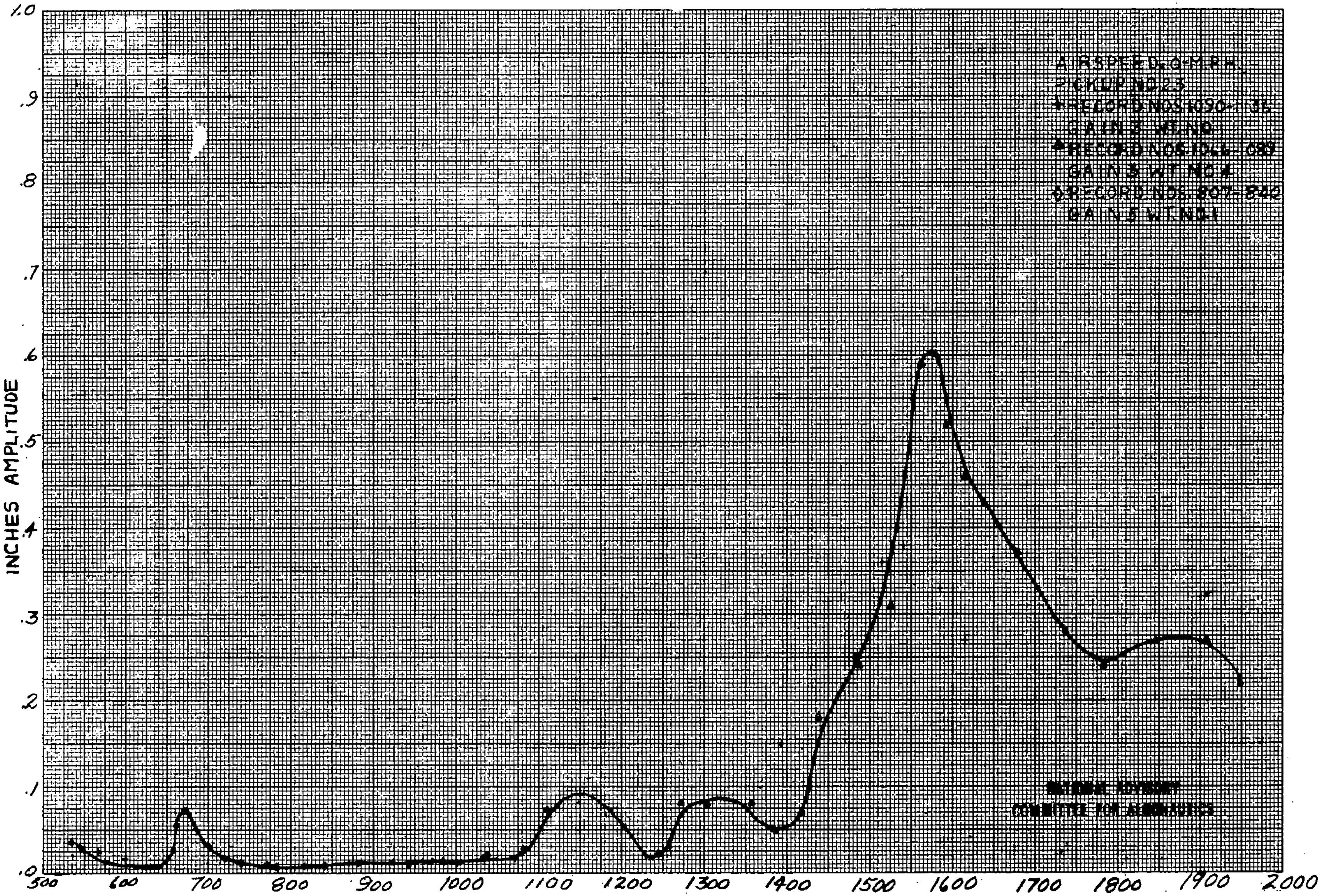
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CYCLES PER MINUTE
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 21



AIRSPEED 0 M.P.H.
PICKUP NO.23
RECORD NOS. 807-840
GAIN 5 WT. NO. 1
INCHES AMPLITUDE
CYCLES PER MINUTE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 22

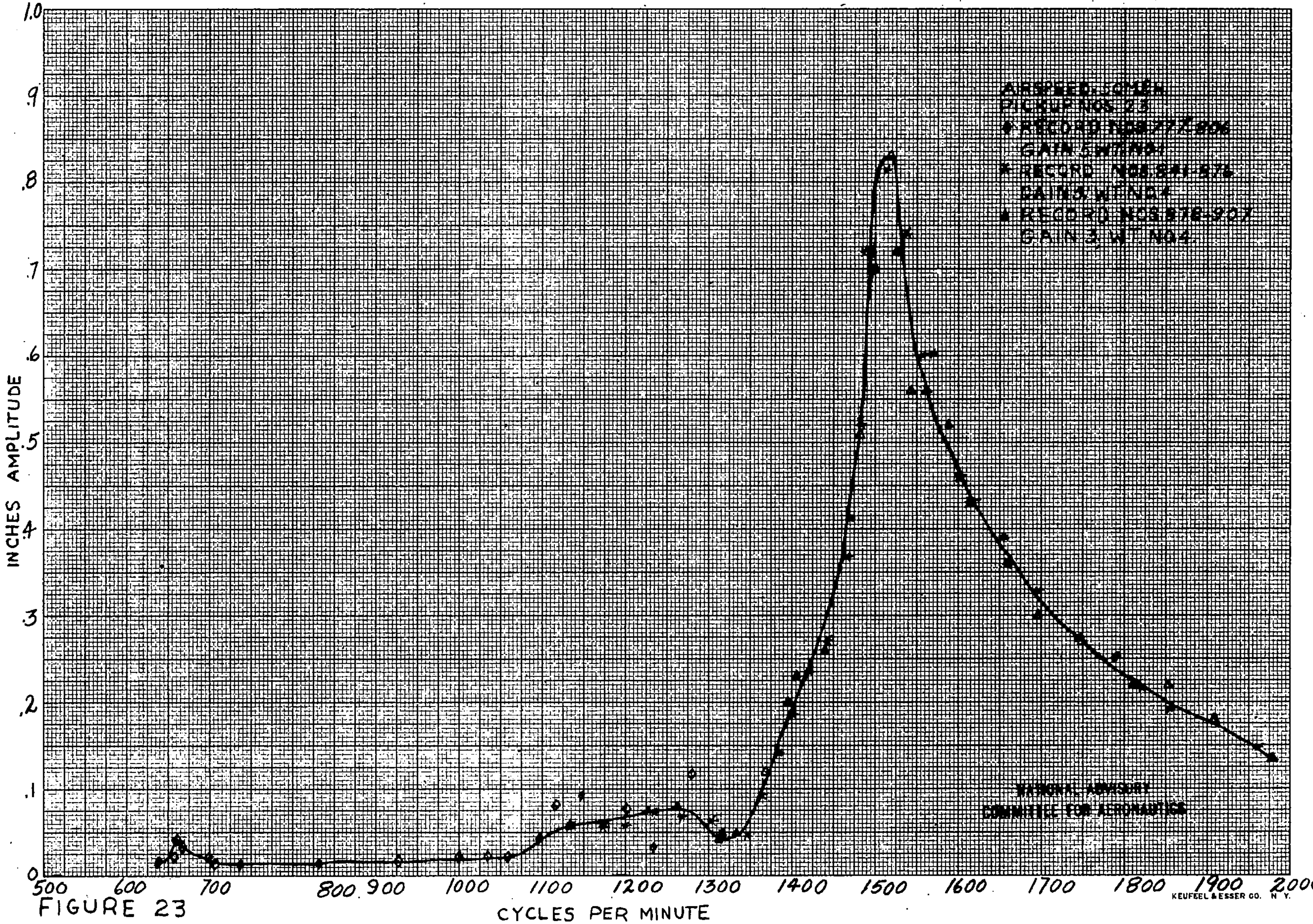

INCHES AMPLITUDE
CYCLES PER MINUTE
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
GAIN 3 WT. NO 4.
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
KEUFFEL & ESSER CO. N.Y.

FIGURE 23

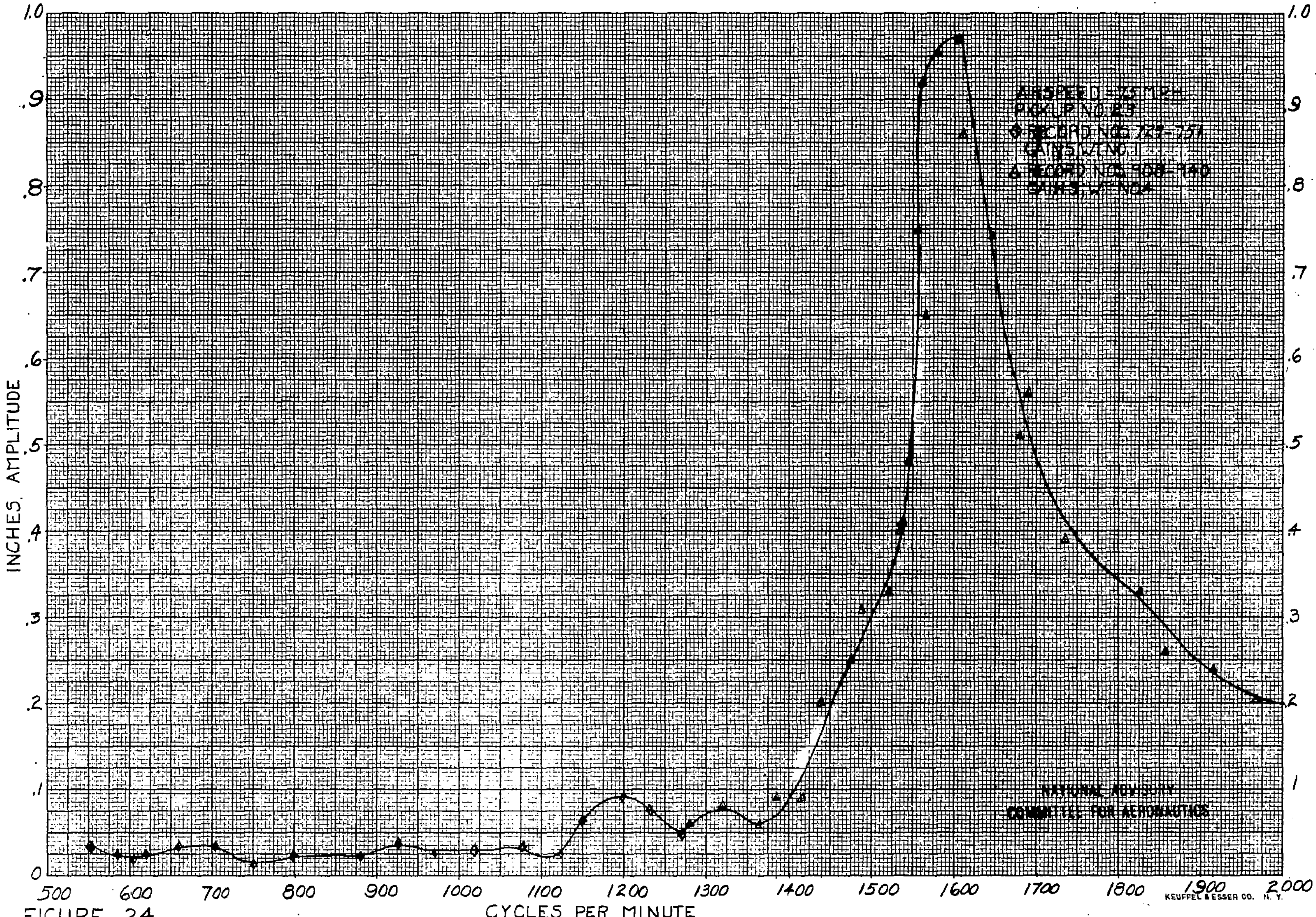

INCHES AMPLITUDE
CYCLES PER MINUTE
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
PICKUP NO. 23
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
KEUFFEL & ESSER CO. N. Y.

FIGURE 24

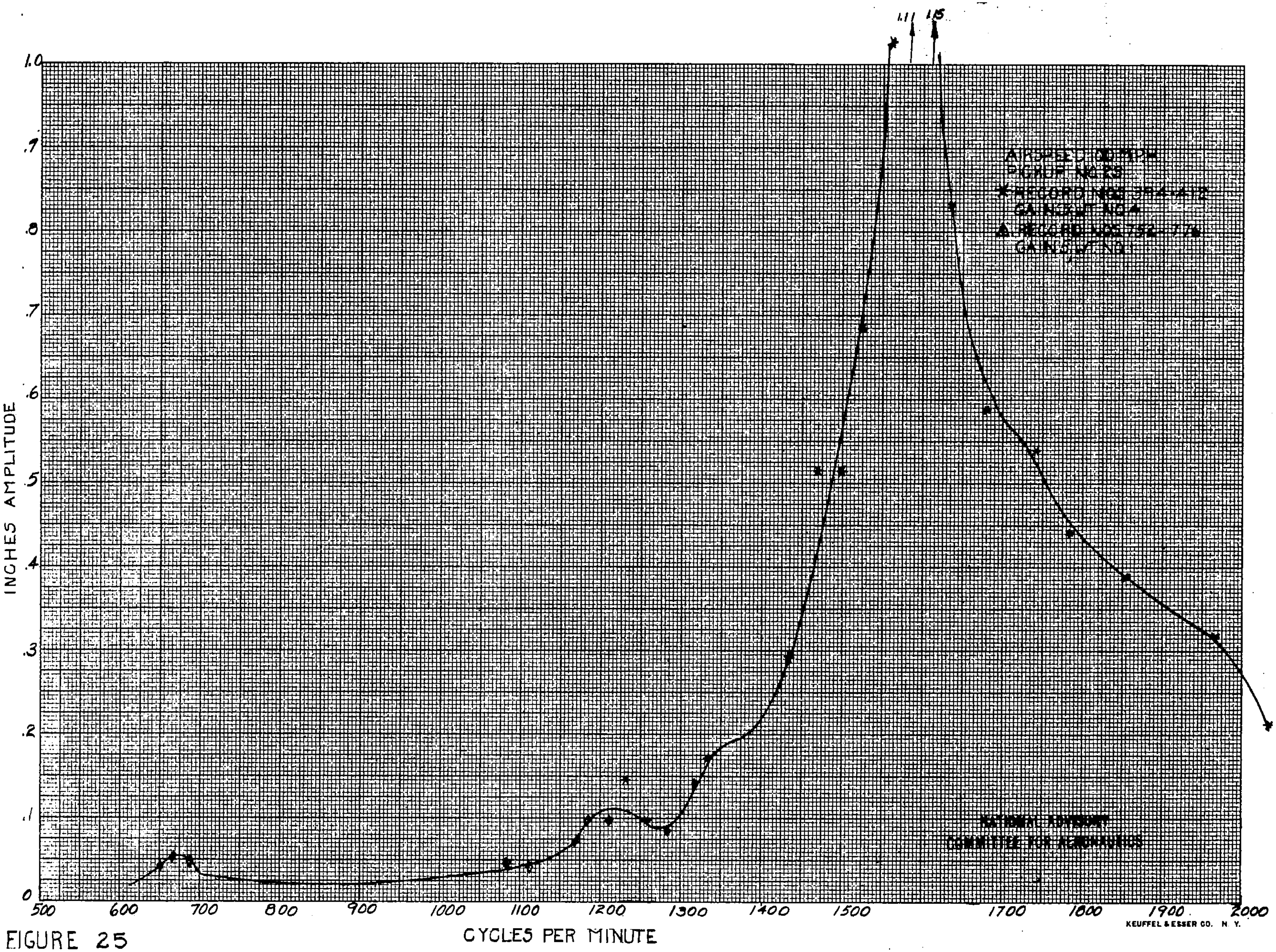

INCHES AMPLITUDE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1700
1800
1900
2000
1.11
1.15
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
CYCLES PER MINUTE
KEUFFEL & ESSER CO. N. Y.

FIGURE 25

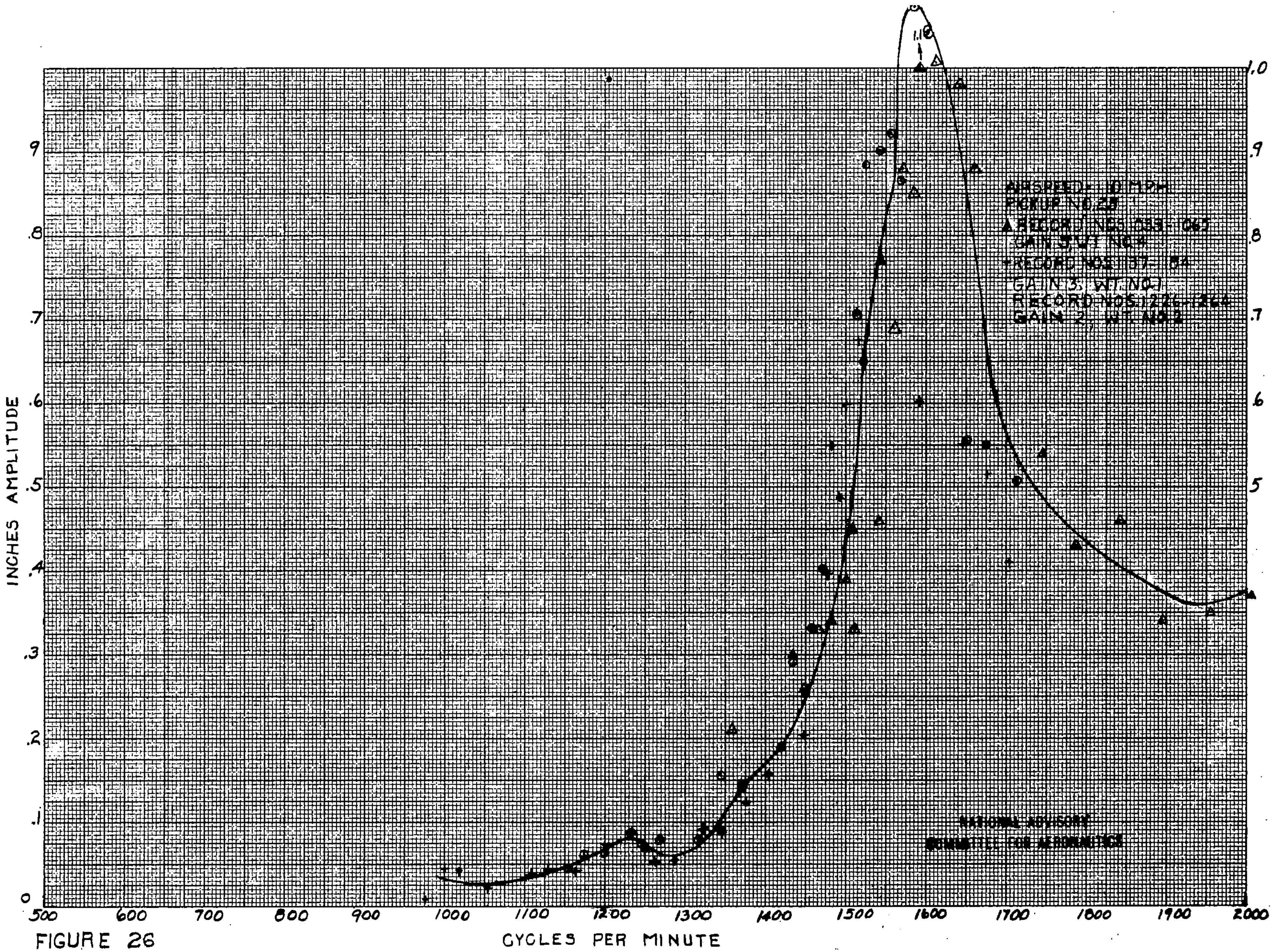

INCHES AMPLITUDE
CYCLES PER MINUTE
GAIN 3, WT. NO. 1
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 26

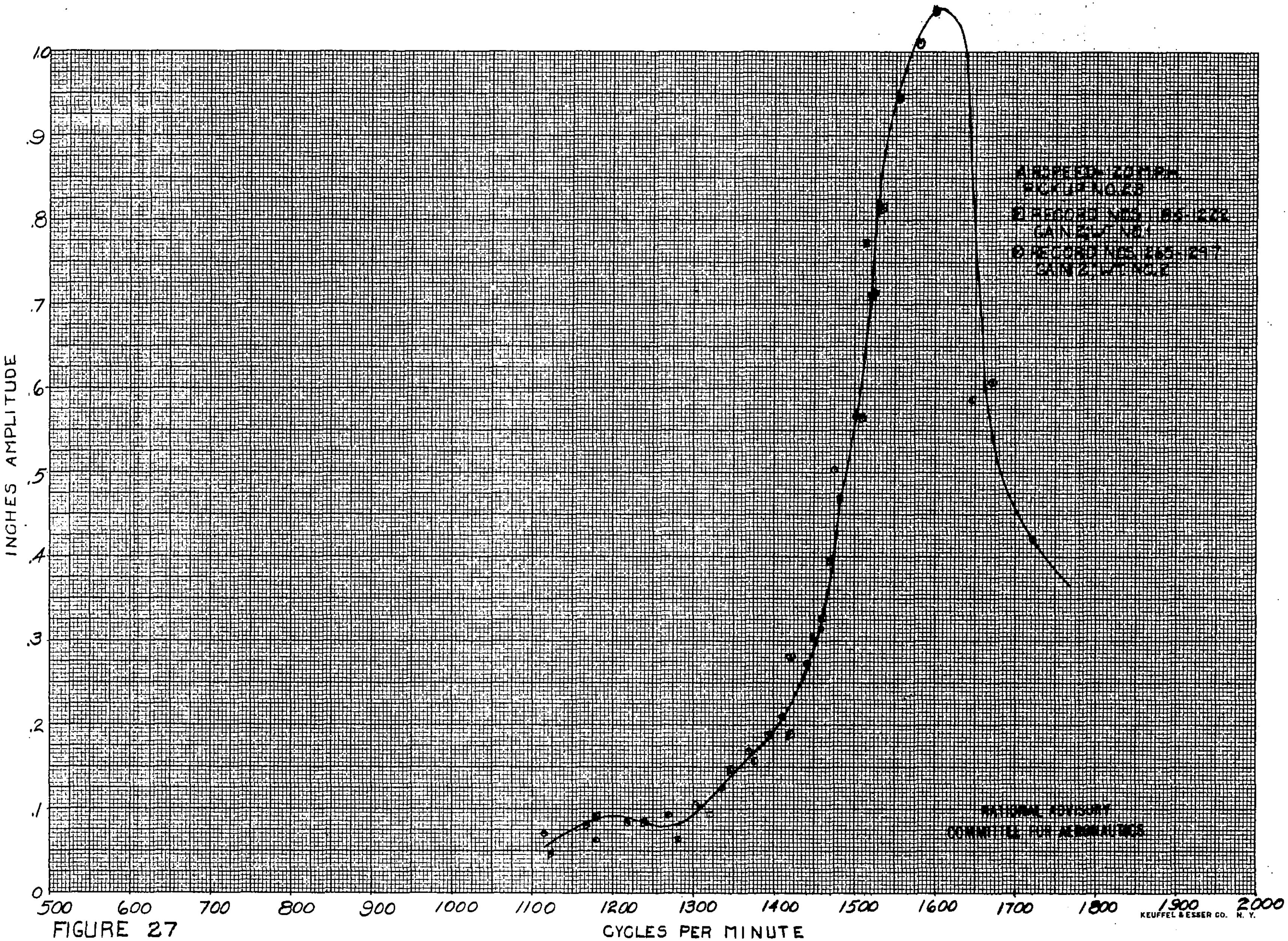

1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
INCHES AMPLITUDE
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CYCLES PER MINUTE
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
KEUFFEL & ESSER CO. N. Y.

FIGURE 27

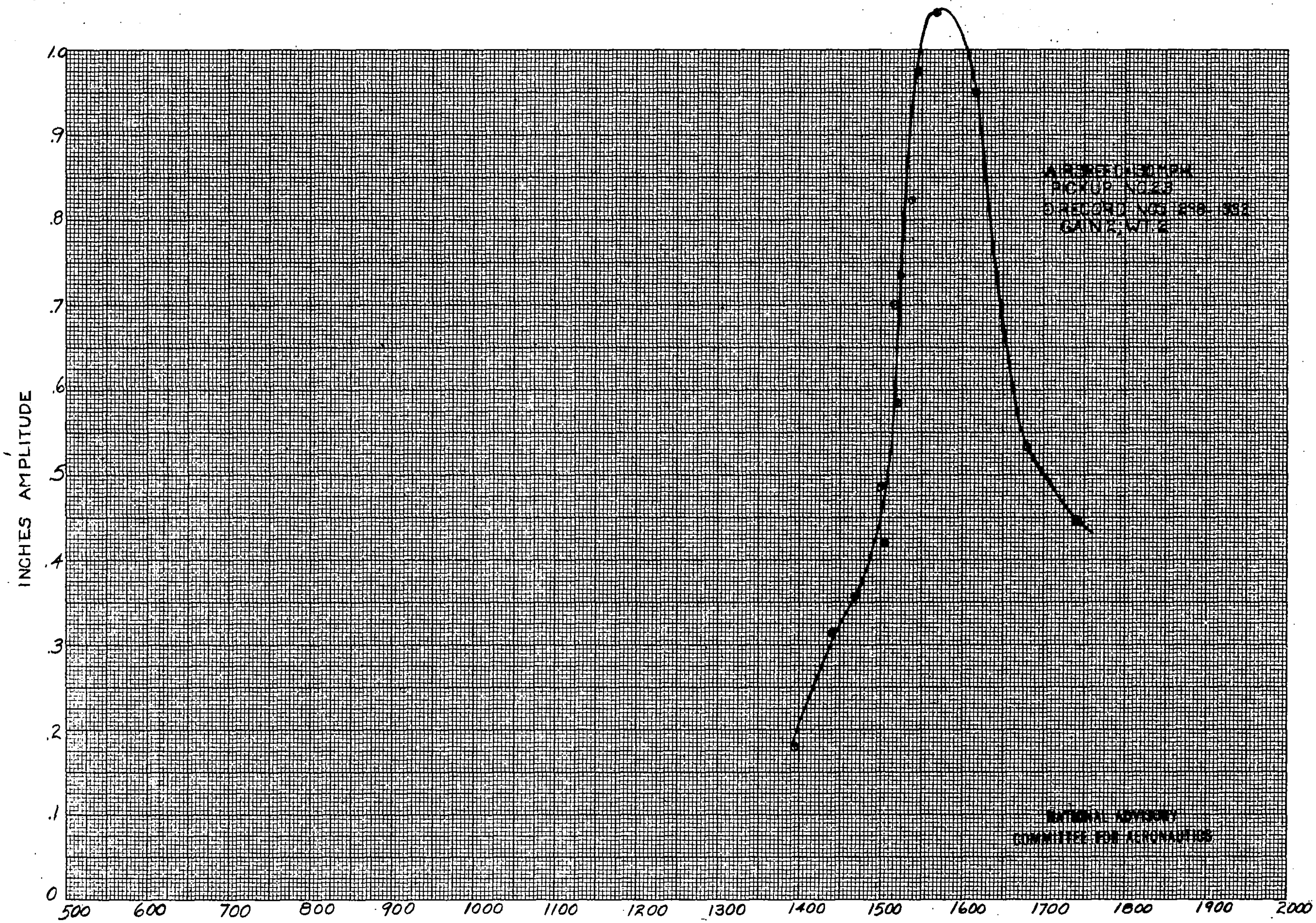
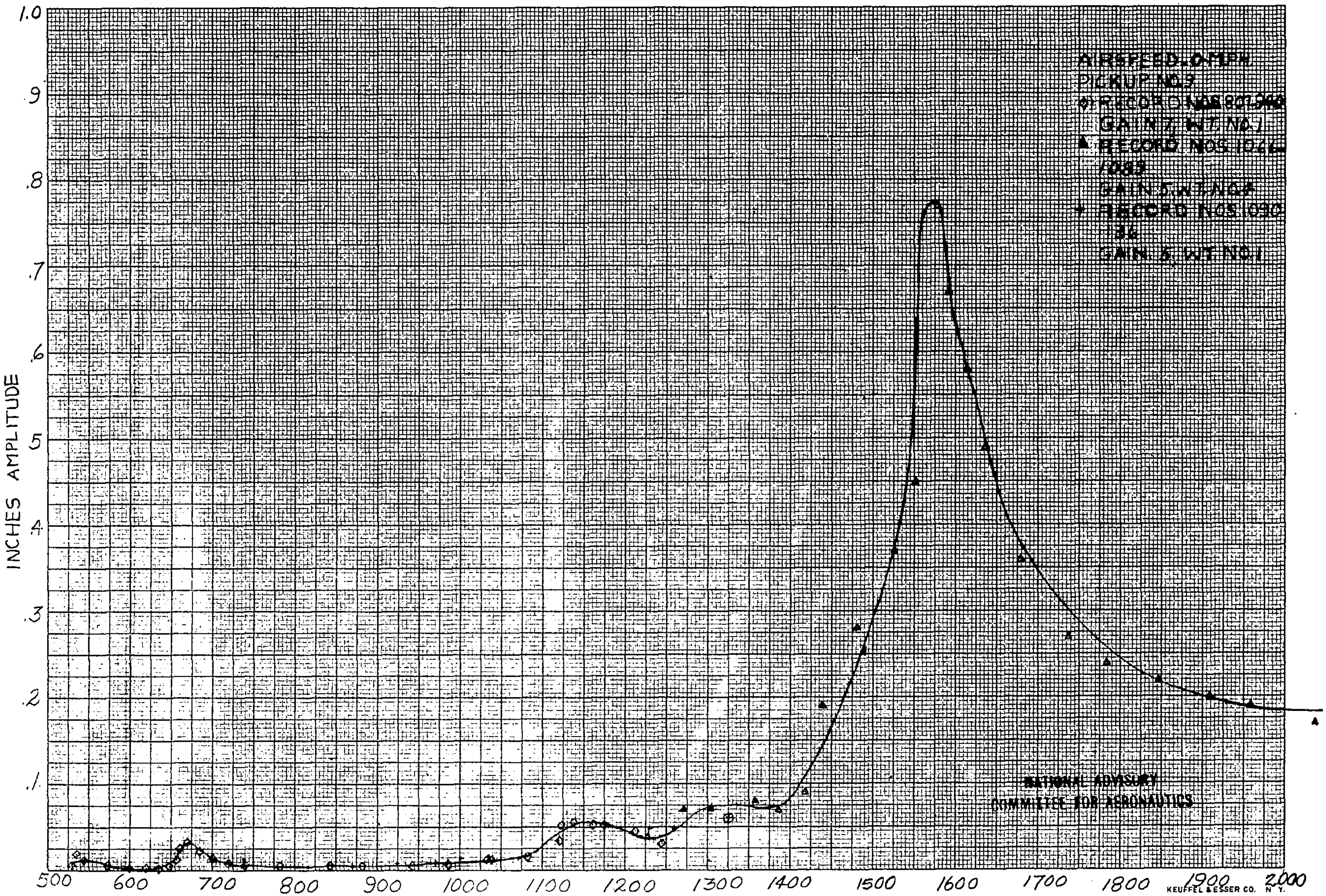

INCHES AMPLITUDE
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CYCLES PER MINUTE
PICKUP NO.23
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 28



AIRSPEED-0-MPH
PICKUP NO.9
RECORD NOS 1062-
1089
GAIN 5, WT. NO.4
RECORD NOS 1090-
GAIN 5, WT. NO.1
GAIN 7, WT. NO.1
INCHES AMPLITUDE
CYCLES PER MINUTE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
KEUFFEL & ESSER CO. N. Y.

FIGURE 29

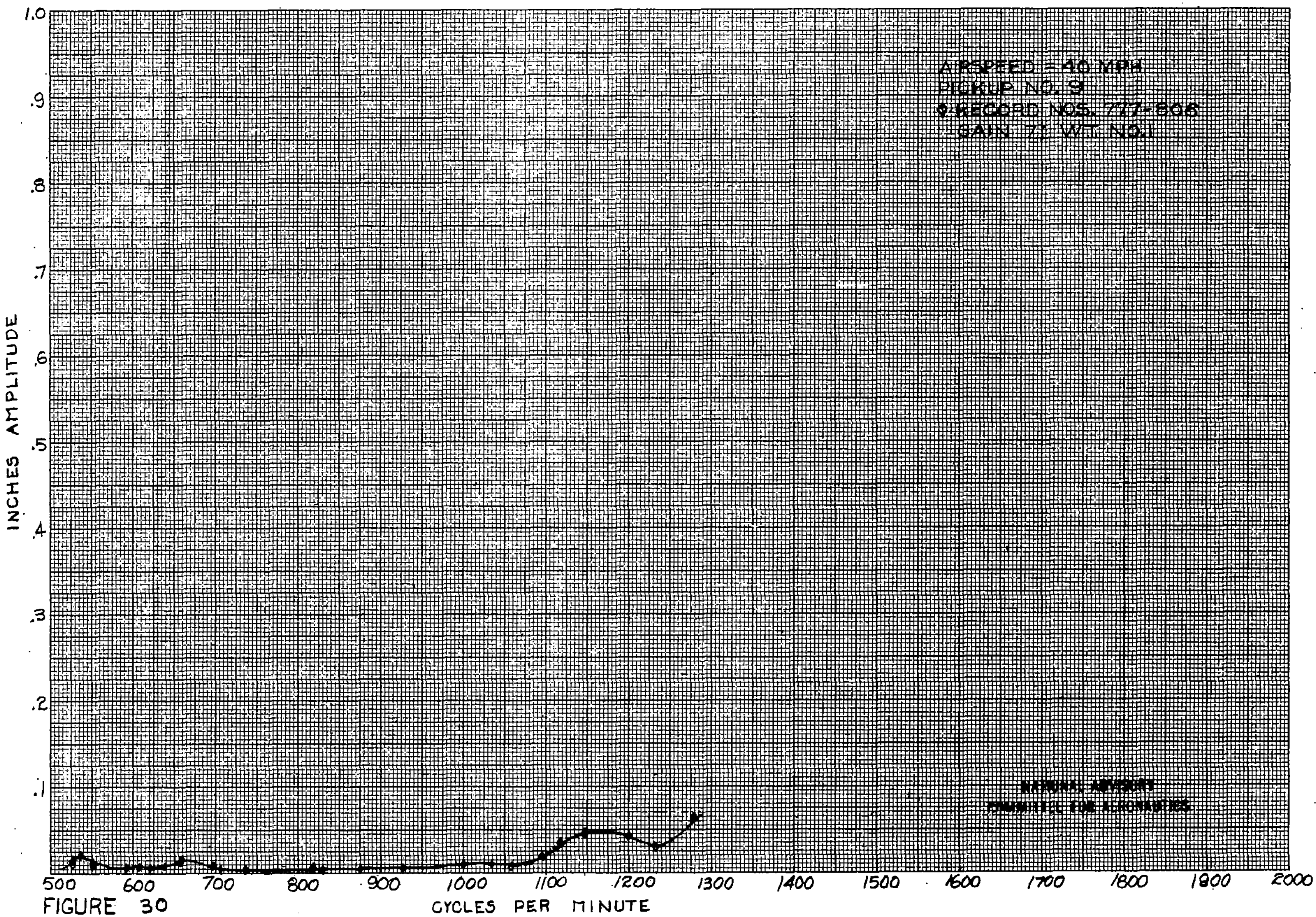

AIRSPEED - 40 MPH
PICKUP NO. 9
RECORD NOS. 777-806
GAIN 7; WT. NO. 1
INCHES AMPLITUDE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CYCLES PER MINUTE

FIGURE 30

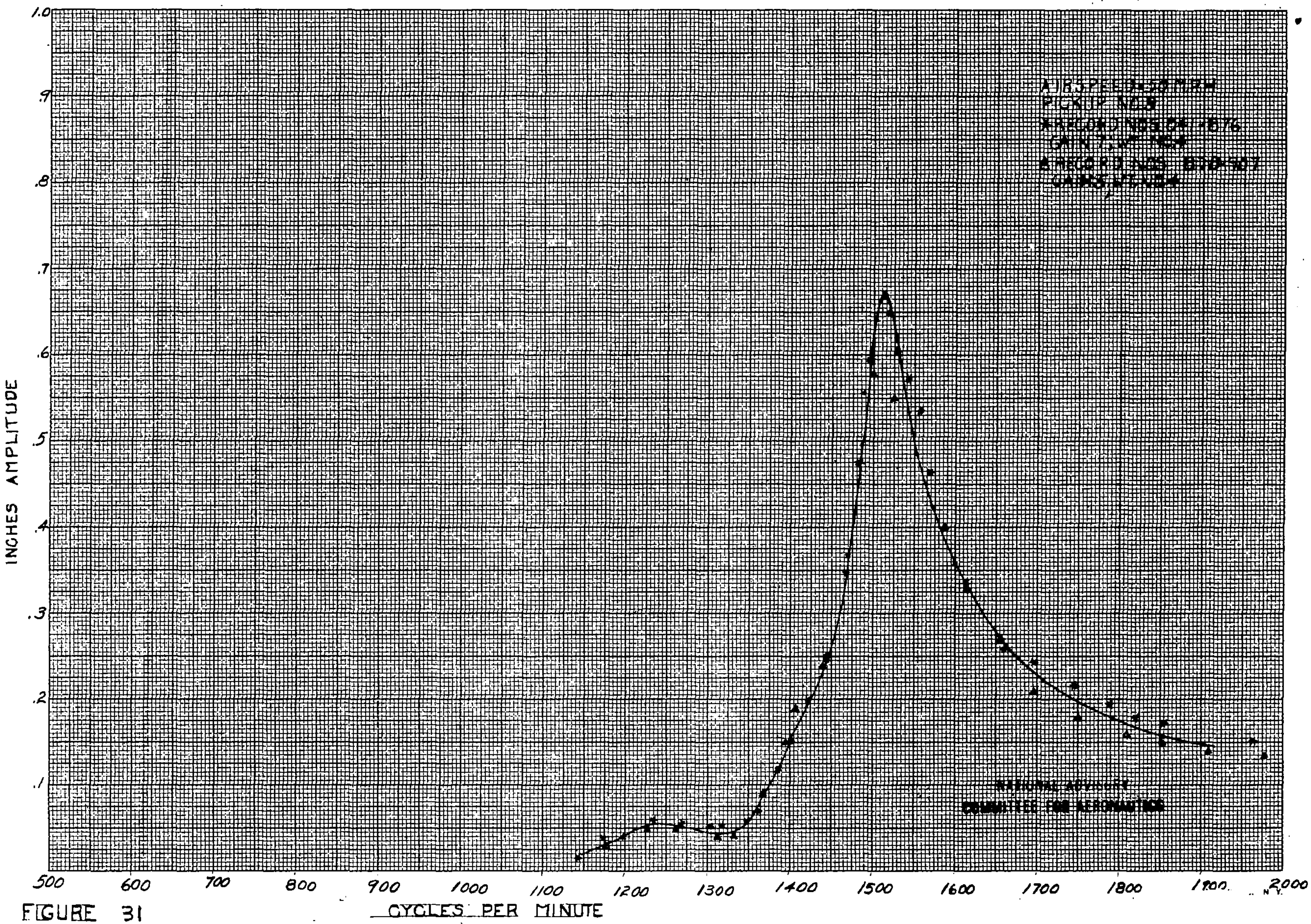

1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
INCHES AMPLITUDE
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CYCLES PER MINUTE

FIGURE 31

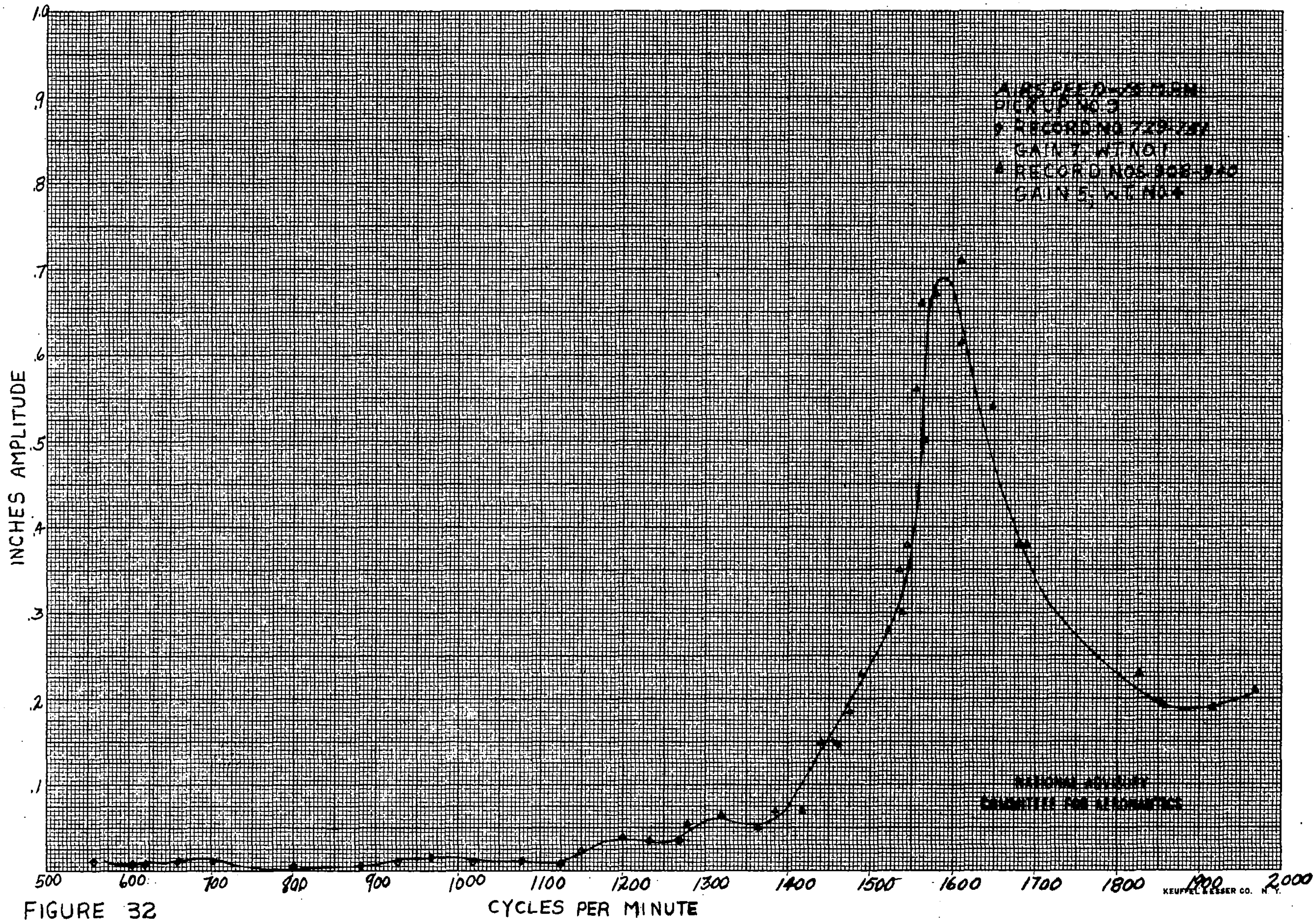

PICKUP NO.3
GAIN 7, W.T. NO.1
INCHES AMPLITUDE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
KEUFFEL & ESSER CO. N. Y.
CYCLES PER MINUTE

FIGURE 32

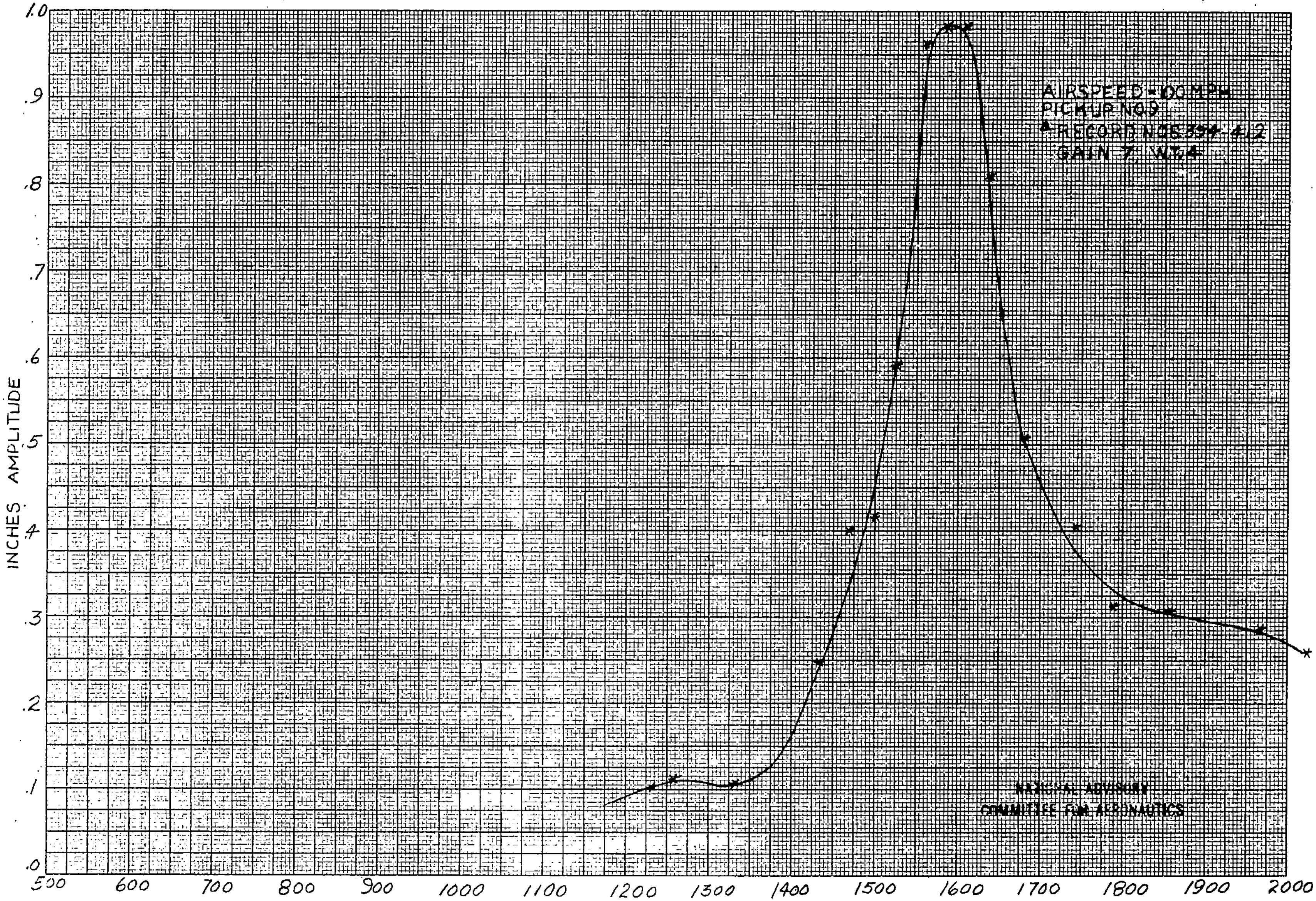
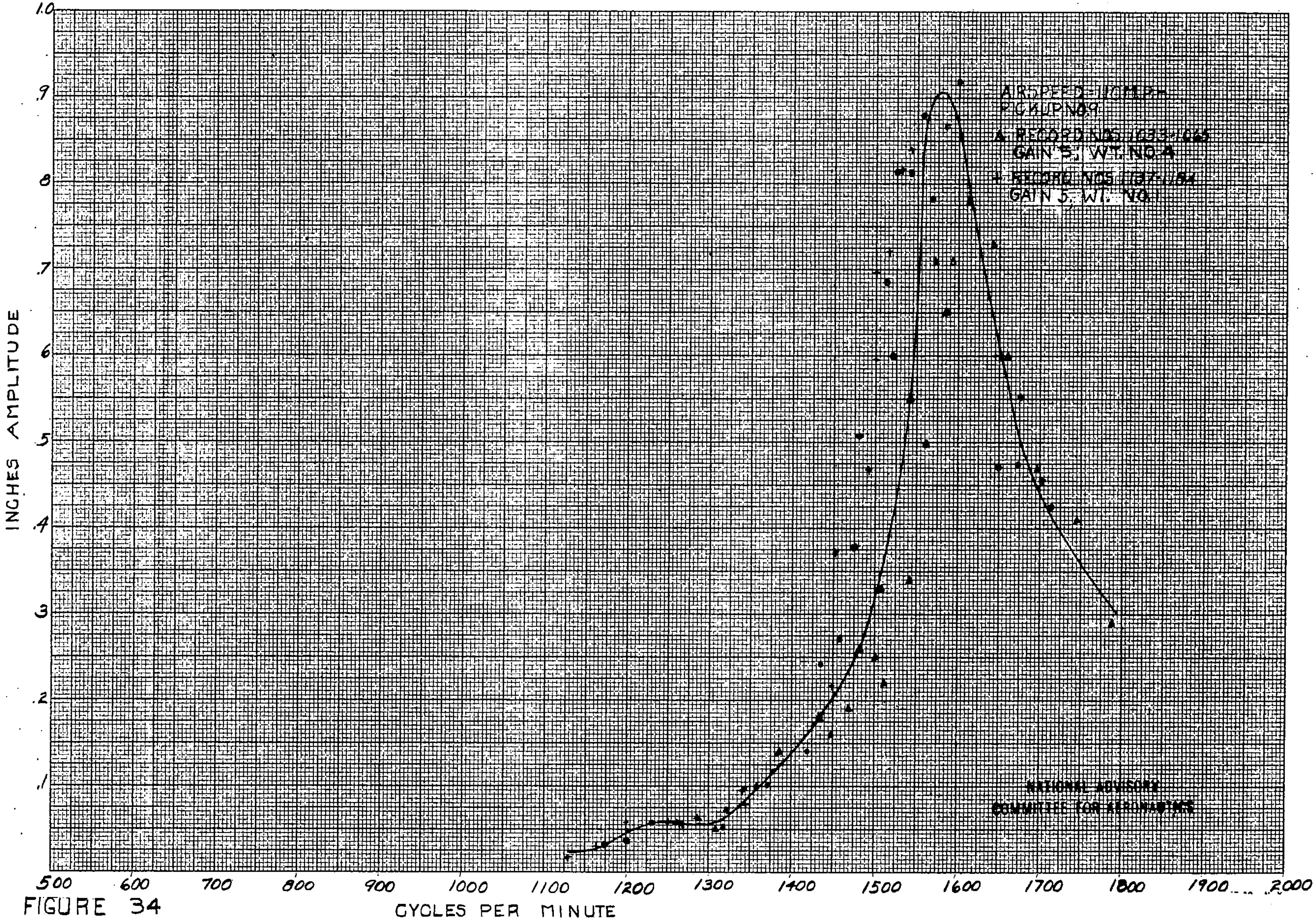

AIRSPEED - 100 MPH
PICKUP NO. 9
RECORD NOS. 394 - 412
GAIN 7, W.T. 4
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
INCHES AMPLITUDE
CYCLES PER MINUTE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 33



AIRSPEED - 110 M.P.H.
PICKUP NO. 9
RECORD NOS. 1033-1065
GAIN 5, WT. NO. 4
RECORD NOS. 1137-1164
GAIN 5, WT. NO. 1
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS
INCHES AMPLITUDE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CYCLES PER MINUTE

FIGURE 34

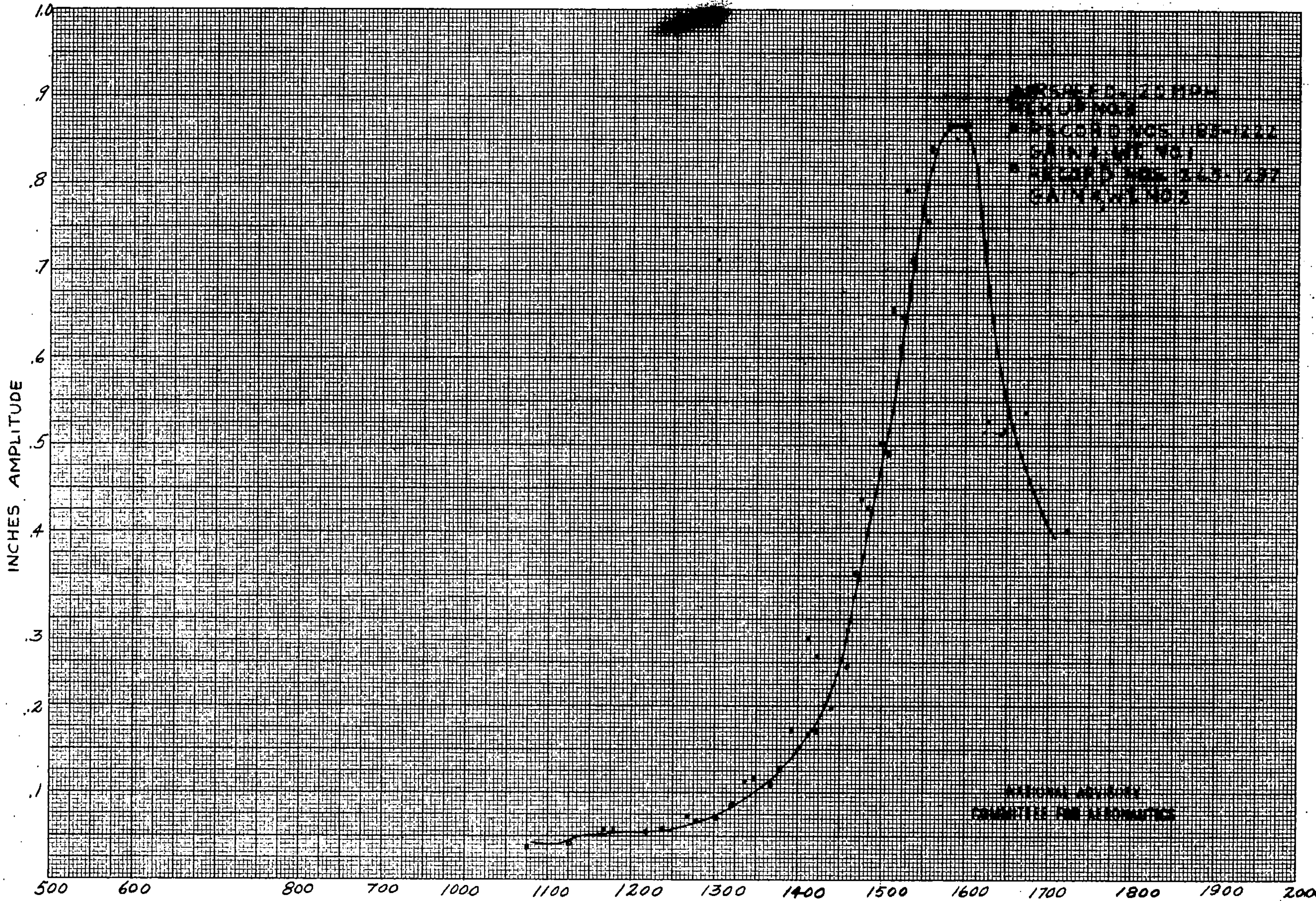
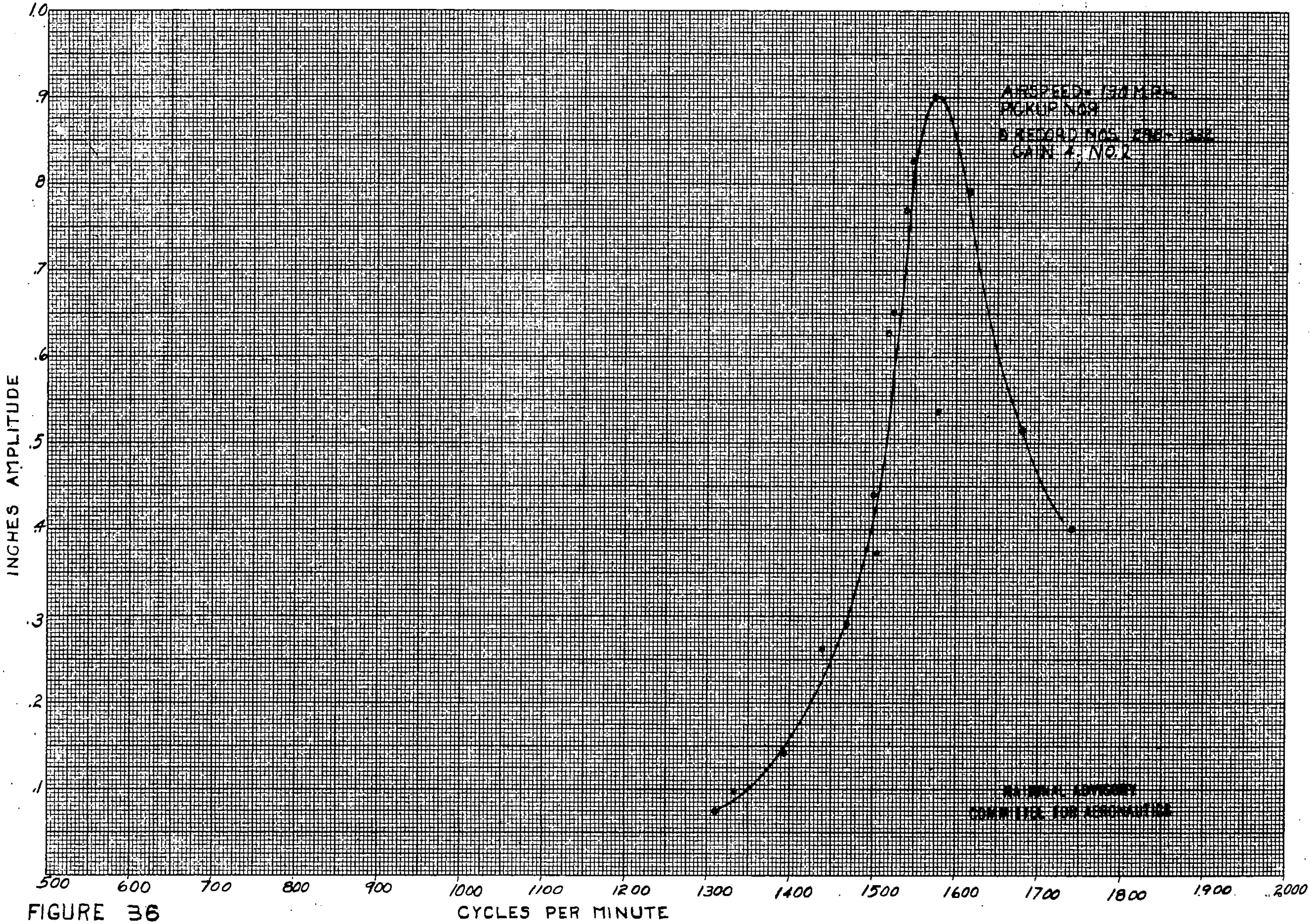


FIGURE 3.5

CYCLES PER MINUTE



INCHES AMPLITUDE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CYCLES PER MINUTE

FIGURE 36

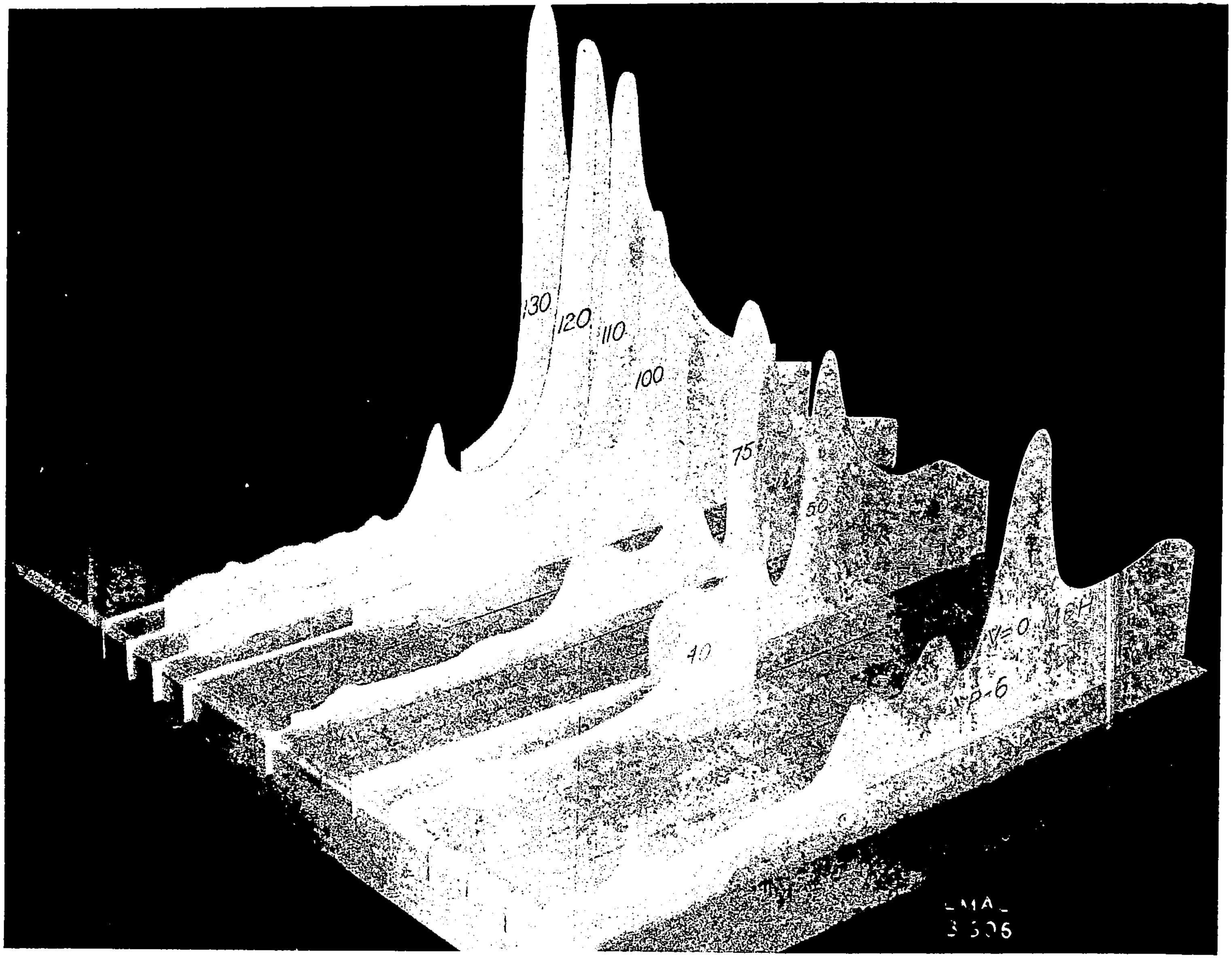


Figure 37a.- Pickup 6, left front.

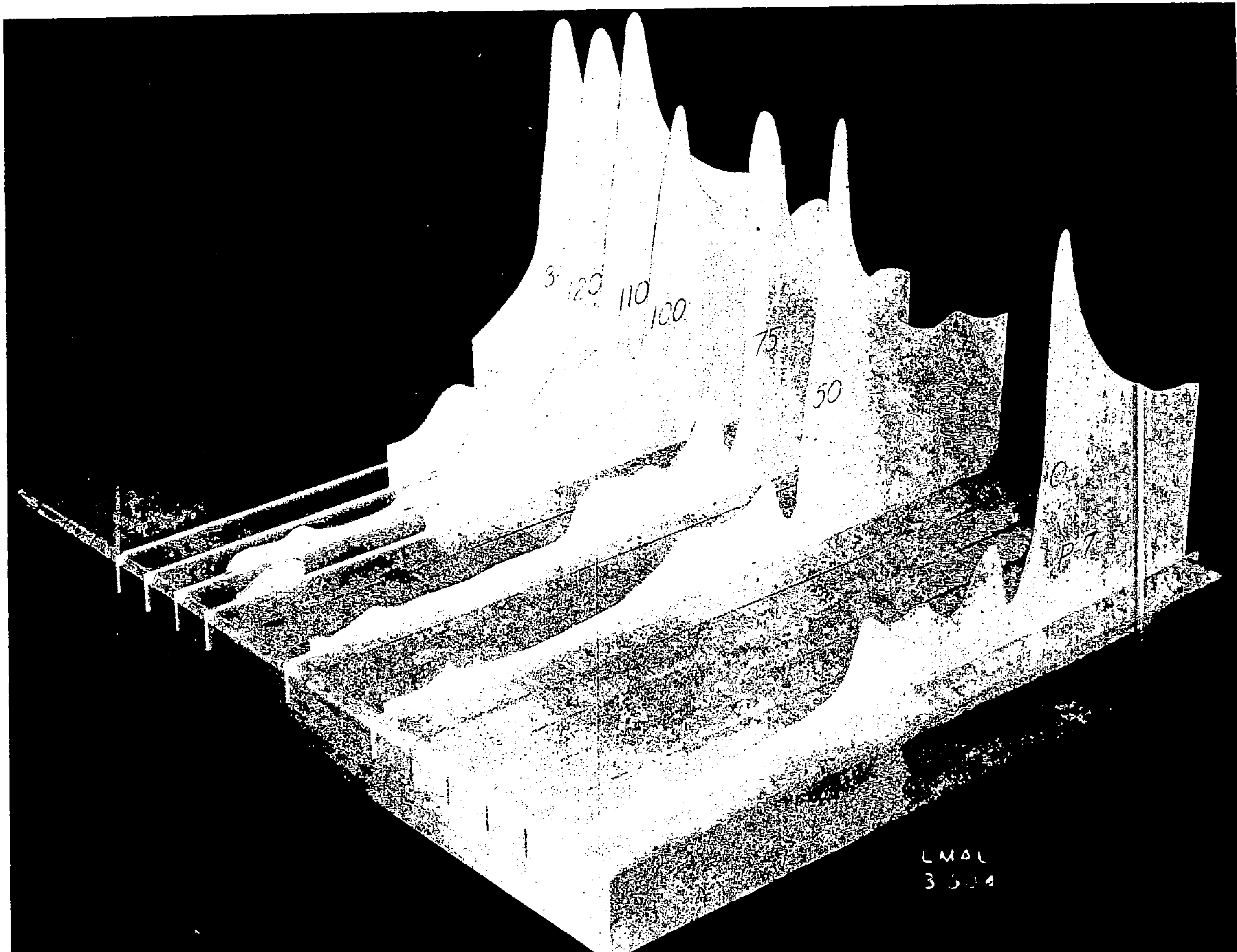


Figure 37b.- Pickup 7, left rear.

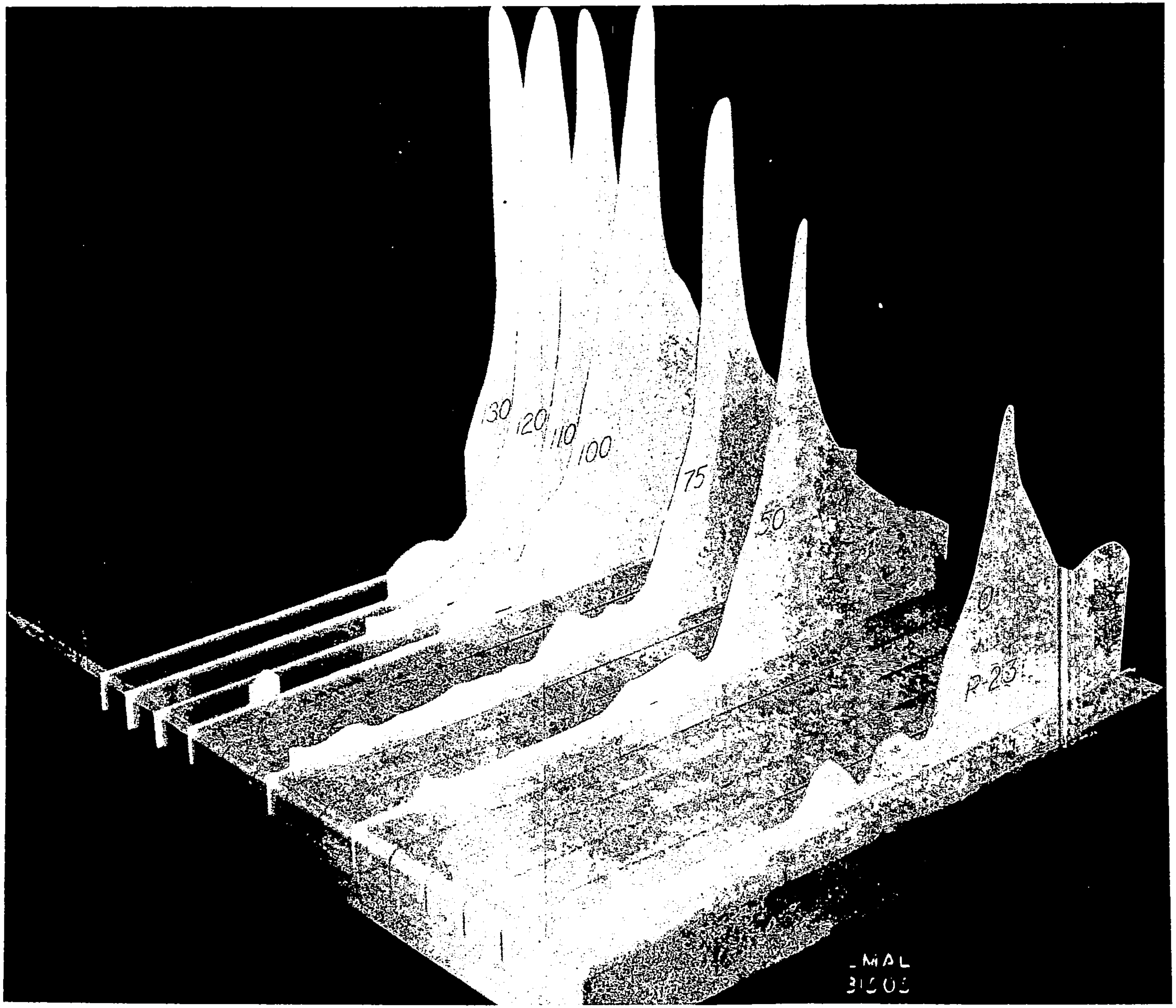


Figure 37c.- Pickup 23, right front.

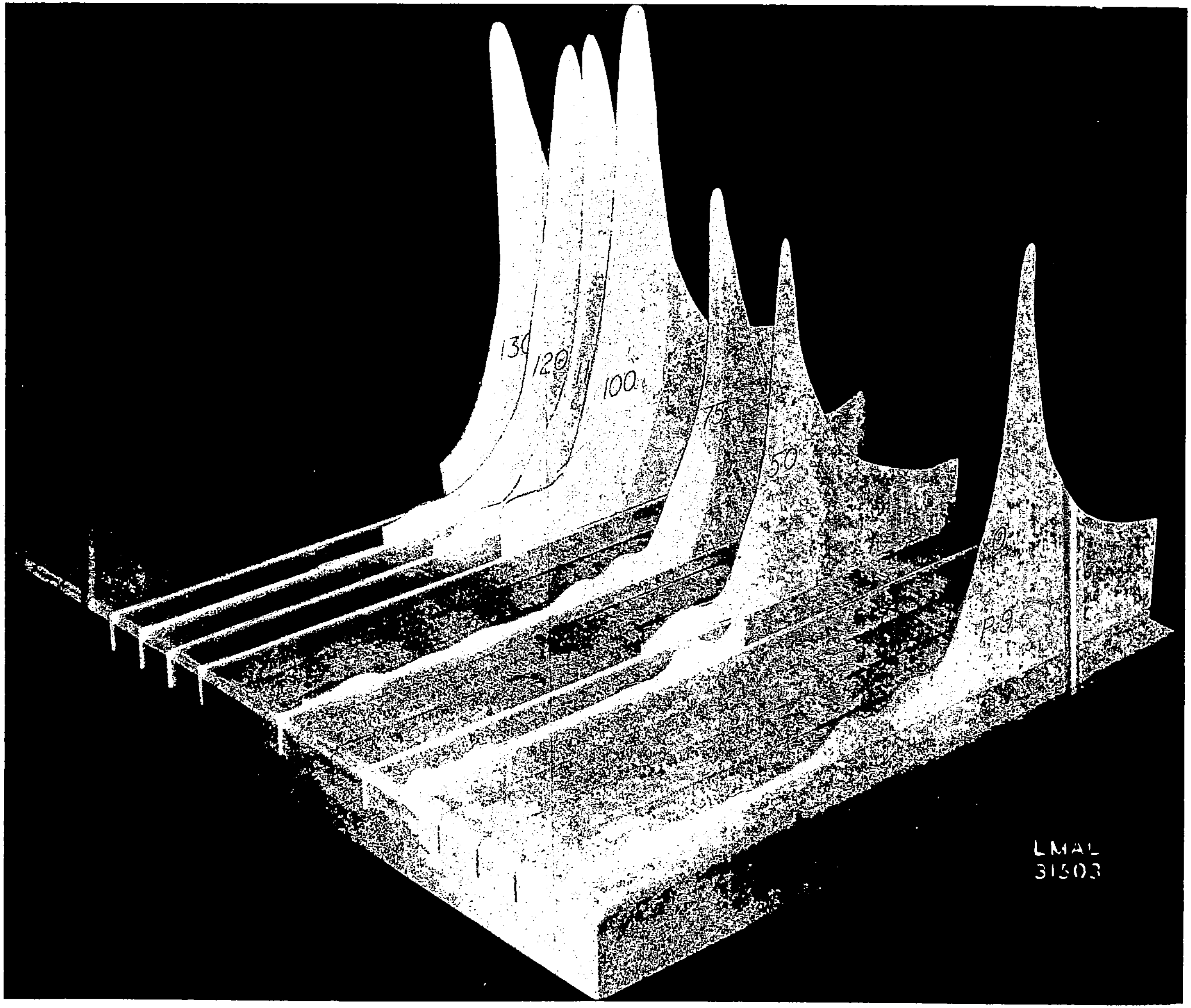


Figure 37d.- Pickup 9, right rear.